

EVALUATION OF A METAL SHEAR WEB SELECTIVELY REINFORCED WITH FILAMENTARY COMPOSITES FOR SPACE SHUTTLE APPLICATION

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PHASE II REPORT

by

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Prepared under Contract NAS1-10860

THE **BOEING** COMPANY

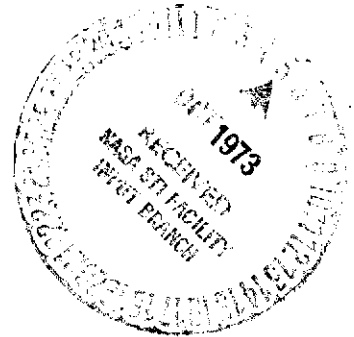
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Langley Research Center

Hampton, Virginia



EVALUATION OF A METAL SHEAR WEB
SELECTIVELY REINFORCED WITH FILAMENTARY
COMPOSITES FOR SPACE SHUTTLE APPLICATION

PHASE II SUMMARY REPORT - SHEAR WEB COMPONENT FABRICATION

By

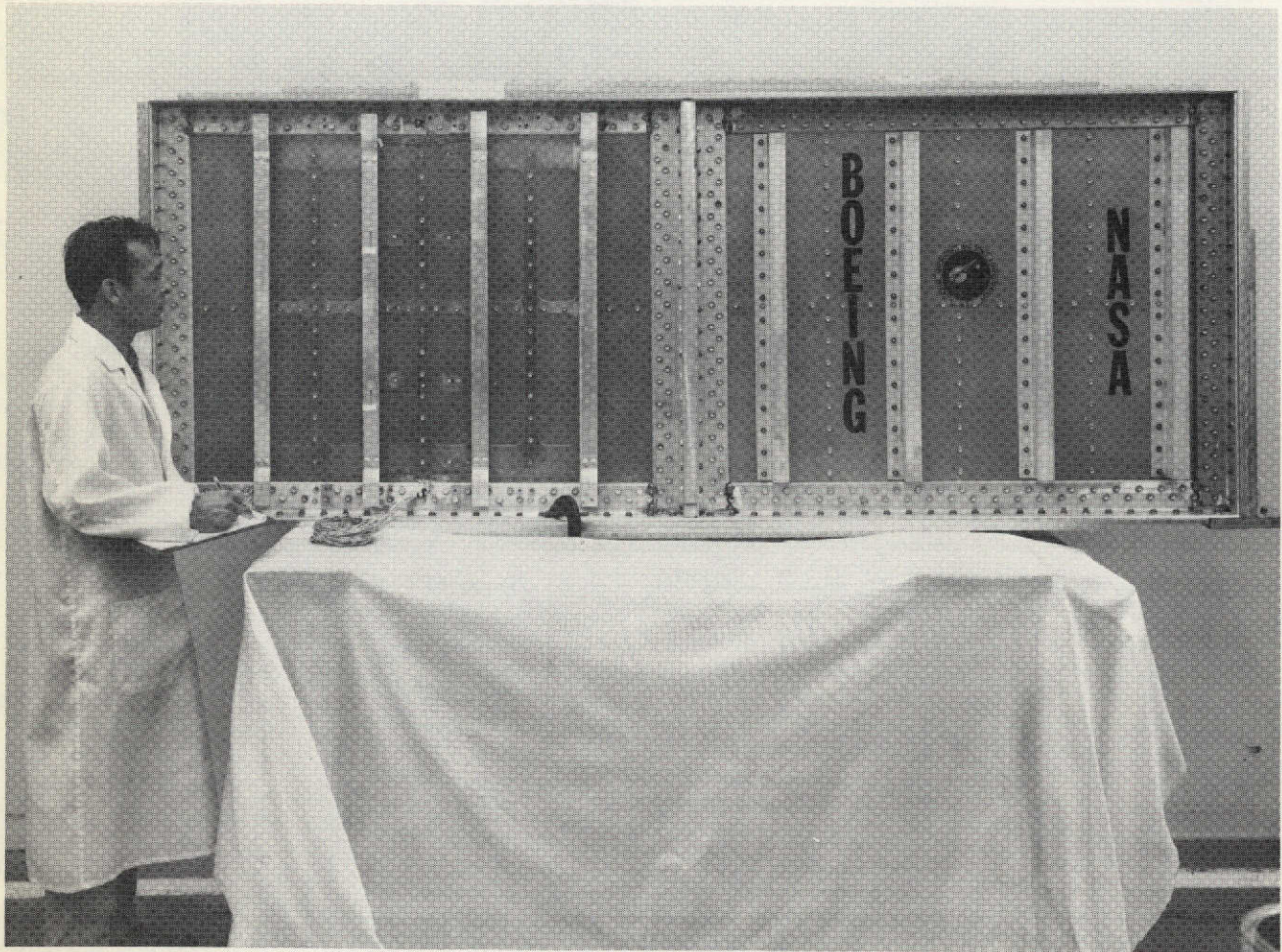
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Prepared by the
Research and Engineering Division
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for

Langley Research Center
National Aeronautics and Space Administration



FRONTISPIECE: TITANIUM CLAD $\pm 45^\circ$ BORON/EPOXY SHEAR WEB

FOREWORD

This report was prepared by the Research and Engineering Division, Aerospace Group, The Boeing Company under NASA Contract NAS1-10860, "Evaluation of a Metal Shear Web Selectively Reinforced with Filamentary Composites for Space Shuttle Application". The program is being sponsored by Design Technology Branch of the Langley Research Center under the direction of the contracting officer's representative, Mr. James P. Peterson.

The technical performance reported summarizes Phase II activities during the period of December 1971 to December 1972.

Performance of the contract is under the management of Mr. Donald K. Zimmerman, Supervisor, Structures Development Group; Mr. John H. Laakso is the Technical Leader. Mr. Dennis D. Smith is the Design Engineer.

The authors wish to acknowledge the contribution of R. E. Nelsen of the Manufacturing Research and Development department and the Composites Fabrication Shop, Everett Nicholson, shop lead.

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1.0 INTRODUCTION

This report presents the results of Phase II of a program for the development of a practical advanced composite shear web concept which is a candidate for near-term application to primary flight vehicle structure. The program consists of three phases:

- Phase I Shear Web Design Development
- Phase II Shear Web Component Fabrication
- Phase III Shear Web Component Structure Testing

The Space Shuttle orbiter main engine thrust beam structure was selected for the shear web application area because of the high shear loading and beam bending strains. These conditions make the use of boron/epoxy (B/E) advantageous. The assumed basic dimensions of the selected center-loaded thrust beam are 40 in. deep by 200 in. span.

In Phase I activities, an integrated design development approach was taken which involved computer-aided design and analysis, detailed design evaluation, testing of unique and critical details, and structural test planning. Particular emphasis was placed on computer-aided design to screen candidate concepts. Various web design concepts having both boron/epoxy reinforced and all-metal construction were synthesized by a comprehensive computer-aided adaptive random search procedure. A data bank of optimum designs for various loading conditions was produced from the computer-aided synthesis activities.

A practical shear web was identified by the design concept evaluation study. This concept had a titanium-clad $\pm 45^\circ$ boron/epoxy web plate with vertical boron/epoxy reinforced aluminum stiffeners. Weight trades showed a 24% savings with the selected concept relative to an all-metal construction. Cost per pound of weight savings was estimated to be less than \$250.

Both the B/E reinforced design concept and the all-titanium web were detailed in design drawings in Phase I. Critical details and reliability considerations for the B/E reinforced design were identified and discussed in Reference 1. Structural element tests were made to substantiate critical area design details. The element tests verified the design concept with respect to local behavior of the details. Cyclic load and temperature design environments were simulated in some of the tests.

Two small scale shear web elements (18 in. by 25 in.) were tested in Phase I to demonstrate the performance of the basic web laminate. Cyclic loading was performed to give assurance that the shear resistant web would meet the 100 flight service life condition. The two web test elements were placed in one side of a center-loaded test beam and loaded to failure at 345,000 lb. and 334,000 lb. Strains exceeding the design requirements were measured during the load tests. In both cases, loading to failure was preceded by 400 load cycles to the limit shear load of 195,000 lb.

Phase II activities were oriented primarily toward the fabrication of three large scale shear web test components. These 36 in. by 47 in. shear web panels were similar to the two 18 in. by 25 in. shear web test elements in design and fabrication process requirements. The fabrication of the two shear web test elements and the three large scale shear web test components is presented in this report.

Test fixtures for the shear web test elements and the large scale web components were also fabricated during Phase II and are reported herein. These center-loaded beam test fixtures were configured to have a test side and a dummy or permanent side. The test fixtures were fabricated from standard extruded aluminum sections and plates and were designed to be reuseable.

2.0 SUMMARY

An advanced composite shear web design concept is being developed for the Space Shuttle orbiter main engine thrust beam structure. Phase I activities, reported in Reference 1, identified a practical shear web concept as having a titanium-clad $\pm 45^\circ$ B/E web plate with vertical B/E reinforced aluminum stiffeners.

Material selection was constrained by the requirements that:

- 1) sufficient material property and process data exist for design;
- 2) the materials are commercially available in quantity, and
- 3) previous experience exist in successful fabrication applications.

The selected materials met all required qualifications. B/E was selected because of its superior strength/density ratio compared to other advanced composites. Titanium was selected over aluminum for its relatively compatible thermal expansion characteristics with B/E and also because of strength/density advantages. Aluminum was adopted for stiffener fabrication because of crippling efficiency considerations.

The boron/epoxy composite was sandwiched between two thin gage titanium cladding sheets to make up the nominal shear web panel. Sixteen plies of B/E reinforcement were layed up in $\pm 45^\circ$ laminates and cured in subassembly form. A subassembly was made from 1 center ply of adhesive, 8 plies of $\pm 45^\circ$ B/E, and a four segment titanium step-lap transition frame. The transition frame allowed mechanical fasteners to be used along the periphery of the web for attachment to chord sections (test fixture or actual shuttle structure).

Each frame was made from 4 segments which were butt joined at the corners. These butt joints were staggered between subassemblies so that one subassembly provided joint rigidity support for the other.

Final assembly bonding joined the two B/E subassemblies with the selectively chem-milled 0.020 in nominal thickness titanium cladding sheets. The cladding was chemical-milled to provide 0.030 in. lands (0.050 in. total thickness) along stiffener lines to reinforce the 0.25 inch mechanical fastener holes. Phase I testing had previously demonstrated that local strains were held to acceptable levels around the holes by the reinforcing lands. The titanium cladding sheets were cleaned and a chemical conversion coat applied to provide a good bonding surface. Final bonding was accomplished in an autoclave after vacuum bagging the webs. Uniform heat-up and cool-down rates were obtained by holding the laminate in a vertical position during the cure cycle.

Stiffeners were selectively reinforced with a unidirectional longitudinal strip of boron/epoxy on the upper flange of the J section. Stiffener fabrication was complicated by combining two materials of dissimilar expansion characteristics in an unsymmetrical configuration. By mechanically restraining the B/E reinforcing cap to the aluminum stiffener at room temperature before bonding the components, residual curvature was reduced to an average 0.050 in. center offset. It is felt that improvements in tooling and a decrease in restraining fastener slippage would further reduce the distortion. The desired flatness of ± 0.005 in. could be obtained, if then required, by machining excess material from the lower flange. An alternate method, using a boron/epoxy infiltrated section, was considered in early trades but was eliminated because of cost considerations.

The fabrication techniques developed for the three large scale shear web test components during Phase II activities are amenable to a tape laying machine. However, since fabrication quantities were low, no attempt was made to utilize this capability.

In-process controls for quality regulation during fabrication was accomplished by close monitoring of workmanship. Nondestructive test techniques, such as radiographic and ultrasonic inspections, were utilized. Good results were obtained on the selected concept shear webs by these nondestructive test techniques in identifying areas of incomplete bonding and flaws. Laminate detail positioning and ply orientation are also inspectable.

This report summarizes the fabrication techniques developed during Phase II. The ability to fabricate large shear webs of high strength with a significant weight reduction has been demonstrated. The three large scale shear web components were successfully fabricated and accepted for testing in Phase III.

3.0 MATERIAL SELECTION

The selection of the materials to be utilized in the shear web considered the requirements that the material be presently available in production quantity, have previously been fabricated in similarly sized components, and have sufficient material and process data available for design. The materials that have been selected for use are Rigidite 5505/4 boron/epoxy (B/E) prepreg for the composite reinforcement, 6Al-4V titanium for the metal portion of the shear web, and Metlbond 329 Type 1A as the primary adhesive system. Table 1 summarizes how the selected materials meet the requirement as specified in the contract statement of work.

Material selection criteria was based primarily on the ability of the materials to meet design requirements and to have a realistic potential for actual shuttle structure. Although an exhaustive material selection trade was not conducted, the selected materials meet all specified and design requirements of this investigative effort.

3.1 Composite Reinforcement

The elevated temperature capabilities and the availability of properties at elevated temperatures of Rigidite 5505/4 boron/epoxy prepreg led to its selection as the composite reinforcing material. Elevated temperature allowances up to 375°F have been developed by Grumman under Contract F33615-68-C-1301. From Grumman's H-33 orbiter ascent flight profile, the assumed temperature conditions were predicted for the upper engine thrust beam and are shown in Figure 1. The 375°F capability of the selected B/E system gives future design growth potential.

Table 1: MATERIALS SELECTION

Composite Reinforcement	Rigidite 5505/4 Boron/Epoxy Prepreg
Metal Cladding	Titanium 6Al-4V
Adhesive System	Metlbond 329

REQUIREMENT	COMMENTS
<ul style="list-style-type: none"> ● Presently available in sufficient quantities to build full scale Space Shuttle components. ● Previously been used to fabricate components on the order of 1/8 in. x 2 ft. x 2 ft. 	<p>All-three material systems are in production status.</p> <p>6Al-4V titanium used in tested SST wing box several magnitudes larger.</p> <p>Rigidite 5505/4 used in Grumman wing box and F-14 stabilizer.</p> <p>General Dynamics F-111 stabilizer and McDonnell-Douglas F-4 Rudder</p> <p>Metlbond 329 was used in the Grumman wing box and F-14 stabilizer.</p>
<ul style="list-style-type: none"> ● Design data for the filamentary composite should be at least 75% complete. 	<p>The Structural Design Guide for Advanced Composites lists all the Rigidite 5505/4 properties at temperatures that are necessary to perform this investigation.</p>

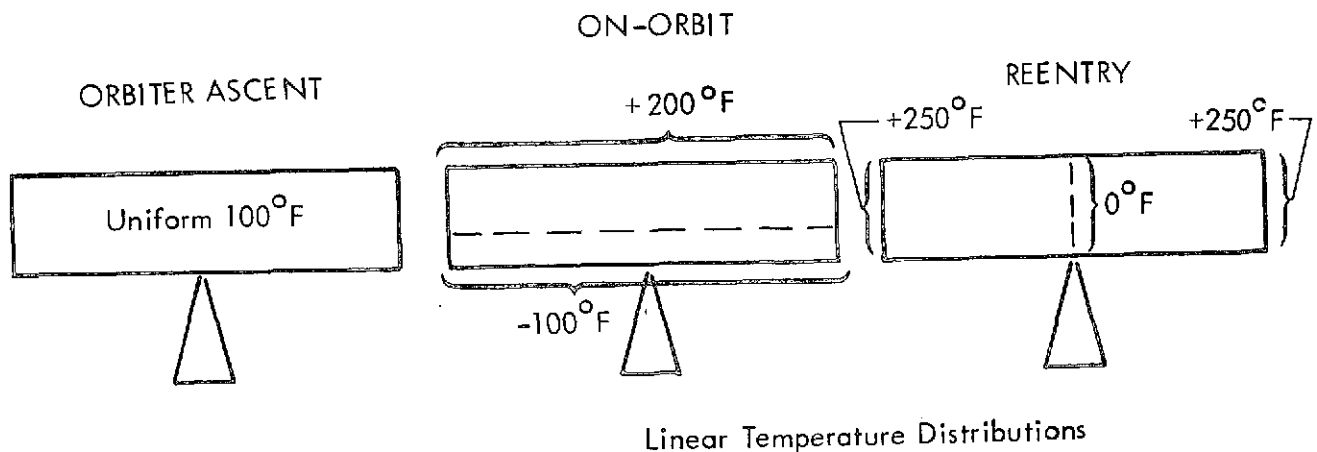


Figure 1: ASSUMED TEMPERATURE CONDITIONS FOR UPPER ENGINE THRUST BEAM

3.2 Metal Cladding

The primary candidates for the metal portion of the shear web design were titanium and aluminum alloys. Aluminum has distinct advantages in cost, available shapes and formability which provides design flexibility. However, in the laminate form with B/E, aluminum has several disadvantages, such as higher bond line stresses with resultant greater distortions. B/E in a $\pm 45^\circ$ laminate has thermal expansion value of $\alpha_x = 4.8 \times 10^{-6}$ in/in/°F while that of aluminum is 13.0×10^{-6} in/in/°F and titanium is 5.3×10^{-6} in/in/°F. It is apparent that there is a considerable thermal mismatch between aluminum and B/E while titanium and B/E are relatively compatible.

The boron composite can be also used in a more efficient manner when reinforcing titanium rather than aluminum. Assuming the allowable critical strains of the reinforcement concepts to be limited by the proportional limit of the metal portion of the web, titanium has a significant advantage as shown in Table 2.

TABLE 2: ALLOWABLE CRITICAL STRAIN
(Established by Proportional Limit)

<u>TEMP.</u>	<u>6Al-4V TITANIUM</u>	<u>7075-T6 ALUMINUM</u>
RT	.0060	.0046
300°F	.0052	.0040
375°F	.0050	.0033

At room temperature and at the reuse temperature of aluminum (300°F), the proportional limit strain of titanium is 30% higher than that of aluminum. The proportional limit strain of titanium is about 50% higher than aluminum at 375°F.

3.3 Adhesive System

Narmco's Metlbond 329 Type 1A was selected as the primary adhesive system that will be used for assembling the web components. This selection was based on available property data at temperatures to 375°F, its strength at elevated temperatures, and its processing similarities with Rigidite 5505/4 boron/epoxy prepreg.

BMS 5-51 (Type 2, Grade 5) was utilized as the secondary adhesive for B/E reinforcement bonding to the aluminum stiffeners and cover sheet. The selection was based on a lower cure temperature (225°F-250°F) to lessen fabrication thermal distortion effects. It was felt that because of the much lower strains in the stiffeners than in the web a lower temperature curing adhesive could be utilized in order to control stiffener distortion.

3.4 Stiffeners

A standard extruded aluminum H section (AND 10140-1403) was selected for use as the B/E reinforced vertical stiffeners on the large scale shear web components. The alloy, 7075, was purchased in the 0 condition. The utilization of aluminum considered the large selection of available shapes and thicknesses and the material crippling efficiency factors.

Shear Web #3 also utilized a AND 10137-1606 extruded aluminum channel for the horizontal stiffener. No B/E reinforcement was used on this stiffener. This stiffener was added to enhance the shear resistant behavior of the web and thereby improve its structural performance.

4.0 FABRICATION OF COMPOSITE REINFORCED SHEAR WEB

The fabrication flow diagram for the large scale shear web component is shown in Figure 2. A detailed Manufacturing Plan for the operations discussed in this section is described in Appendix B.

4.1 Titanium Step-Lap Frame

Titanium 6Al-4V was selected for the subassembly step-lap transition frame shown in Figure 3. The four steps were chemical-milled from 0.063 in. sheets with step thicknesses patterned to the thickness of 1 ply of 5505/4 B/E prepreg (0.0055 in.). Subassemblies of shear webs #1 and #2, however, had progressive thinning noted in the transition area caused by resin flow. The resin flow occurs at the edge of the laminate and fills gaps between the ends of a ply and the next step. After final assembly bonding, this thickness variation was also noted on the web surface. Figure 4 illustrates the assembly thickness variation of shear web #2. Fastening vertical stiffeners to the non-plane web surfaces of shear webs #1 and #2 required hand fitting of the stiffeners to the web. To reduce this thickness taper in the transition area, nonuniform steps were incorporated into the step-lap frame of shear web #3. Figure 4 also shows how the nonuniform steps significantly reduced the assembly thickness variation in the step-lap frame area. The step dimensions used on shear web component #3 are shown in Figure 5.

The unique spliced attachment fitting was subjected to considerable testing during Phase I activities to verify its structural integrity. The corners of the 18 in. x 25 in. shear web test elements were carefully examined to identify problems associated with the staggered butt joint concept. In shear

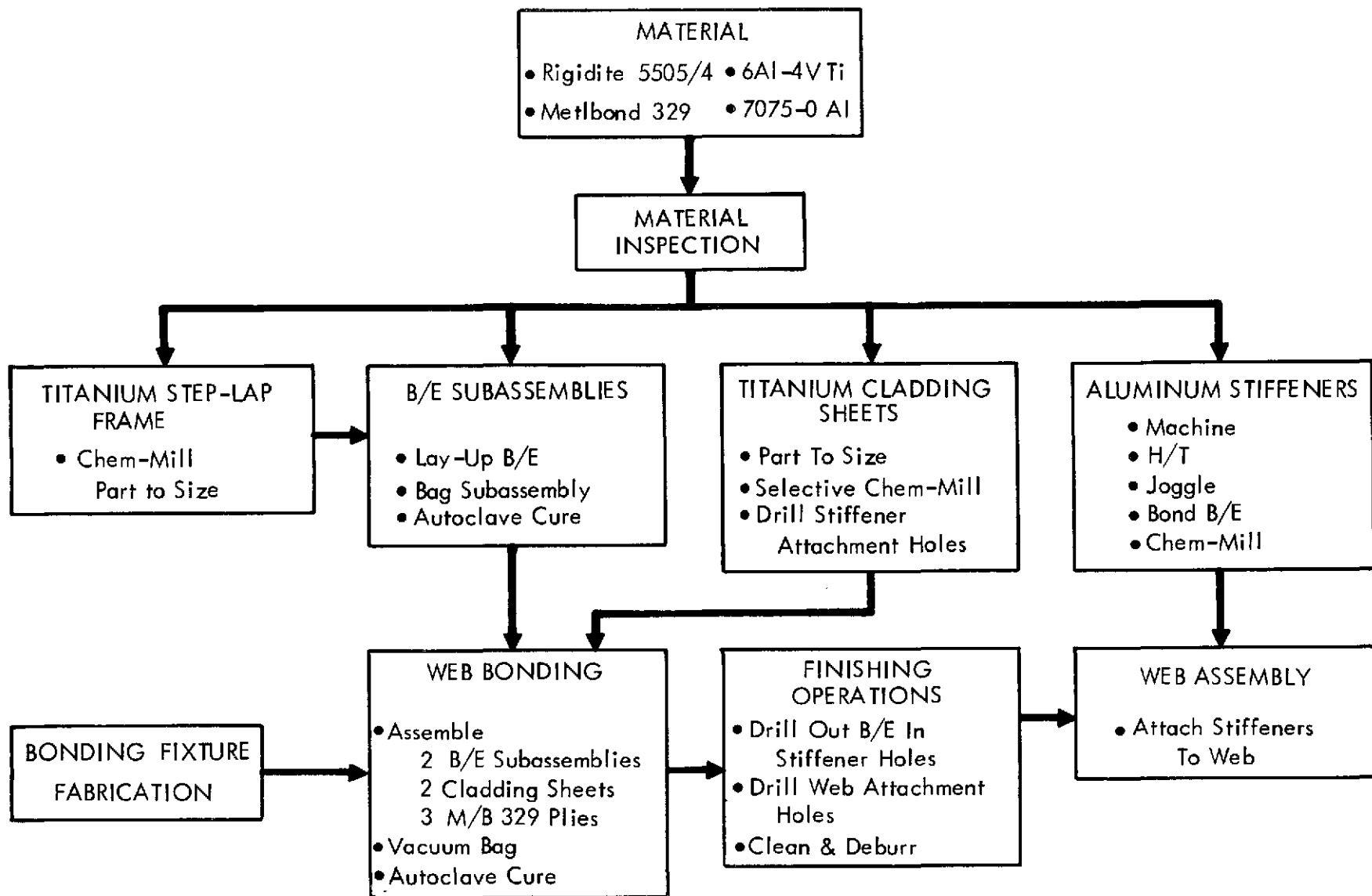


Figure 2: SHEAR WEB FABRICATION FLOW DIAGRAM

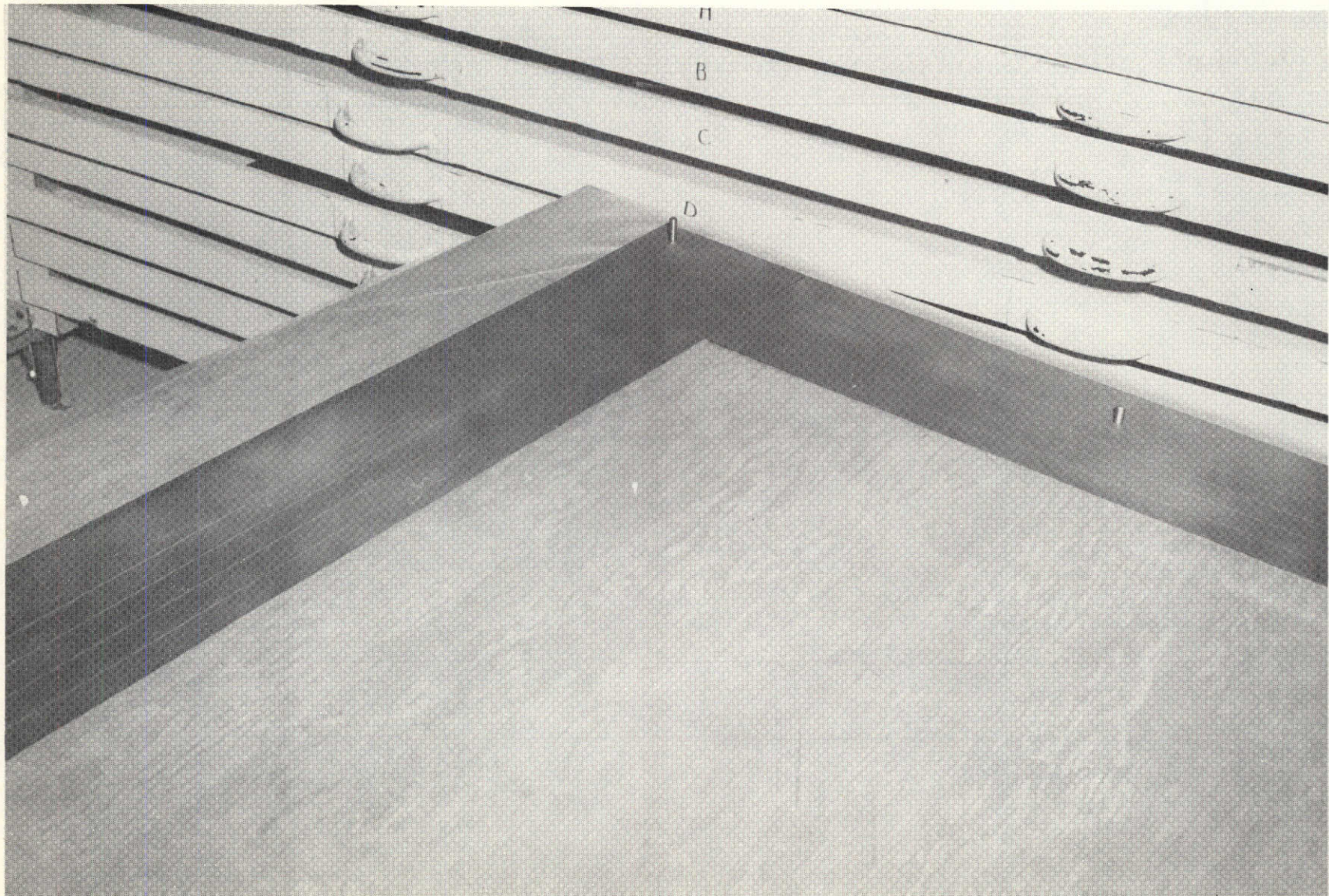
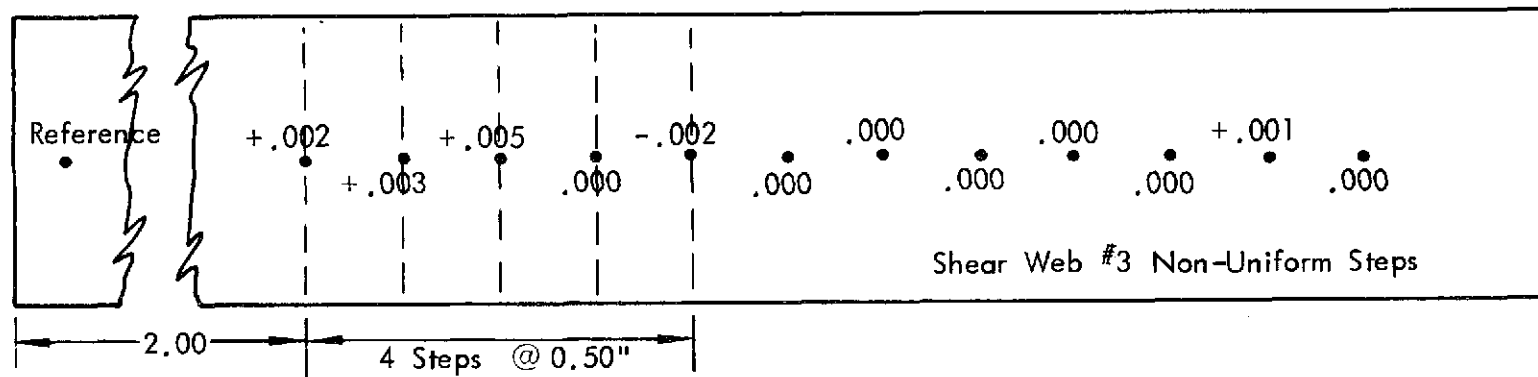
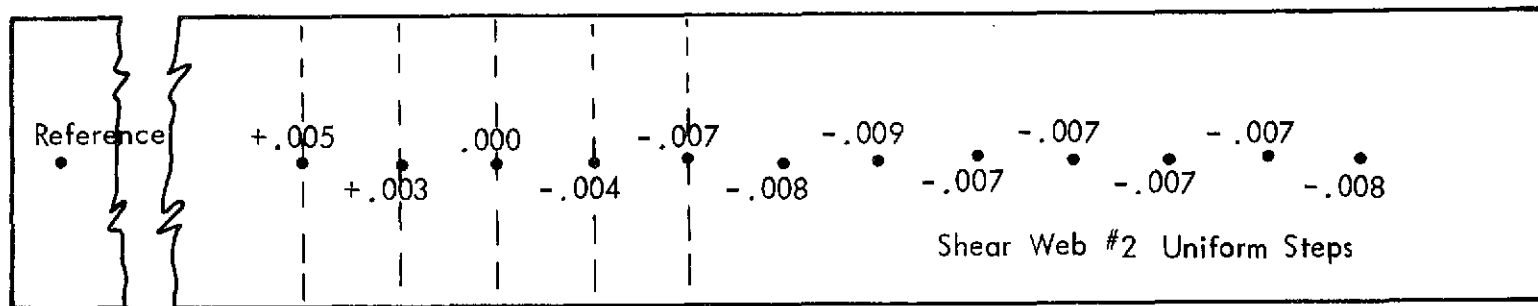


Figure 3: FOUR SEGMENT TITANIUM STEP LAP TRANSITION FRAME



PLAN VIEW

Figure 4: LARGE SCALE SHEAR WEB TEST COMPONENT

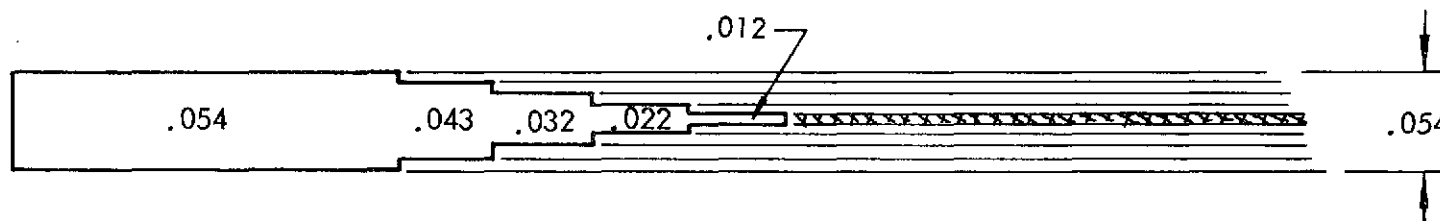


Figure 5: SUBASSEMBLY TITANIUM STEP-LAP DETAIL

web element #1, after testing, the cladding skins were removed by chemical-milling to expose the corner details as shown in Figure 6. No damage or movement at any of the joint splice areas was apparent.

Shear web test element #2 was radiographically inspected after testing. The films substantiated the earlier data of no apparent damage. Additional Phase I testing was conducted on two corner elements which were cycled 400 times to limit load and then failed in tension. The elements simulated the corner areas in the design web under diagonal tension loading. Corner test element #2 was also subjected to 400 thermal cycles from -100°F to +250°F. The design ultimate strain was exceeded in both tests before failure occurred in the B/E area, demonstrating that the butt-spliced step-lap details have sufficient strength capability for the large scale shear web test panels.

The titanium step-lap attachment fitting faying surfaces were cleaned prior to bonding by dry abrasive blasting. Aluminum oxide (150 grit) was used as the abrasive. The abrasive cleaning was followed by a dry, filtered air blast and a silane rinse.

Scotch-Weld brand EC 2333 primer (3M Company) was applied immediately after cleaning and the parts were stored in a clean polyethylene bag until used.

4.2 Titanium Cladding Sheets

The metal cladding sheets were fabricated from 0.063 in. 6Al-4V titanium sheets per design drawings SK2-5085-117 and -138 (shown in Appendix A). Figures 7 and 8 show the cladding sheets for the shear web test element and the large scale shear web test component. The baseline thickness requirements for the shear test elements and the large scale shear webs were determined in Phase I to be 0.020 in. This was the minimum thickness fabrication constraint utilized in the computer-aided design coding. Cladding sheet thickness was

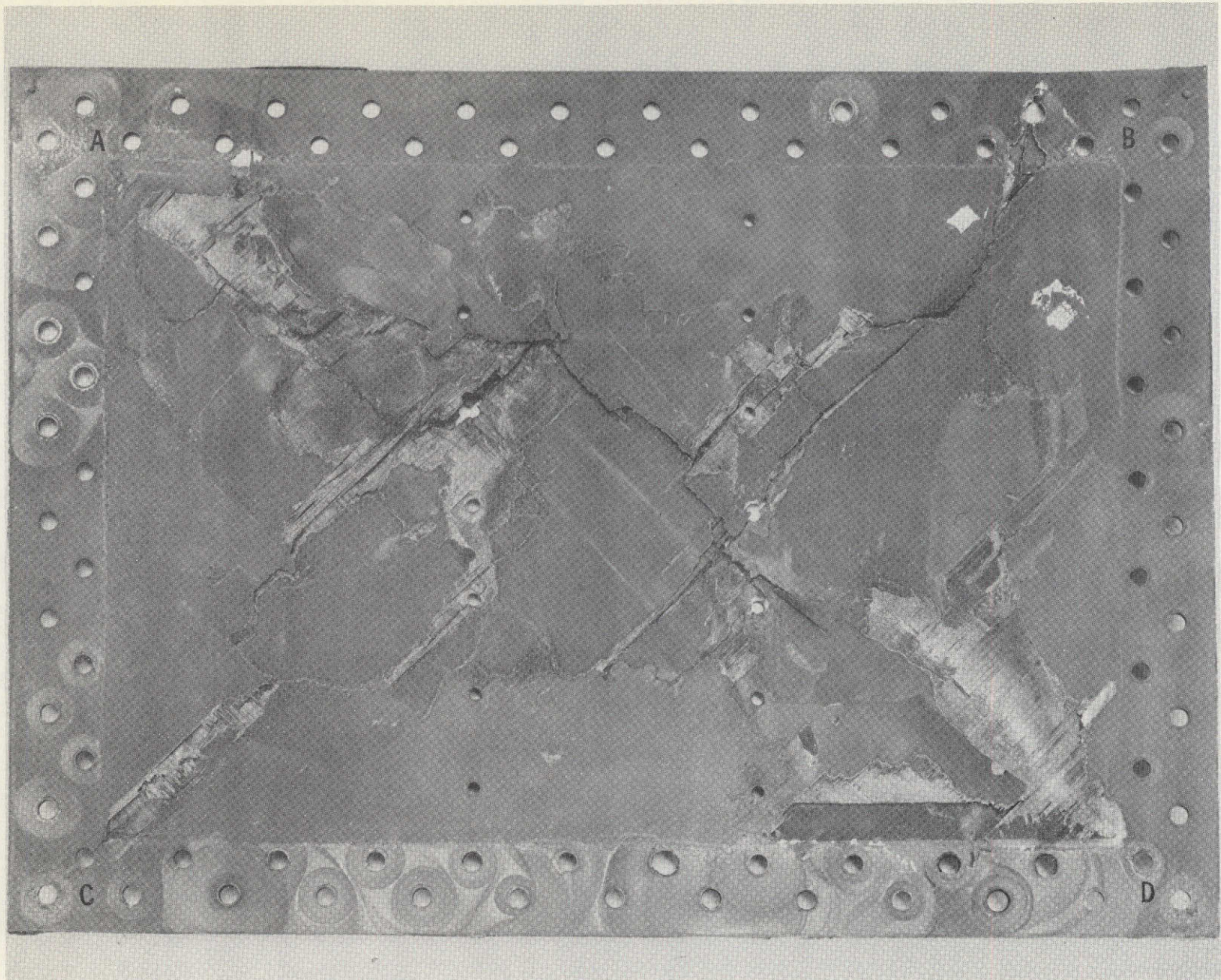


Figure 6: SHEAR WEB TEST ELEMENT AFTER TESTING (CLADDING REMOVED)

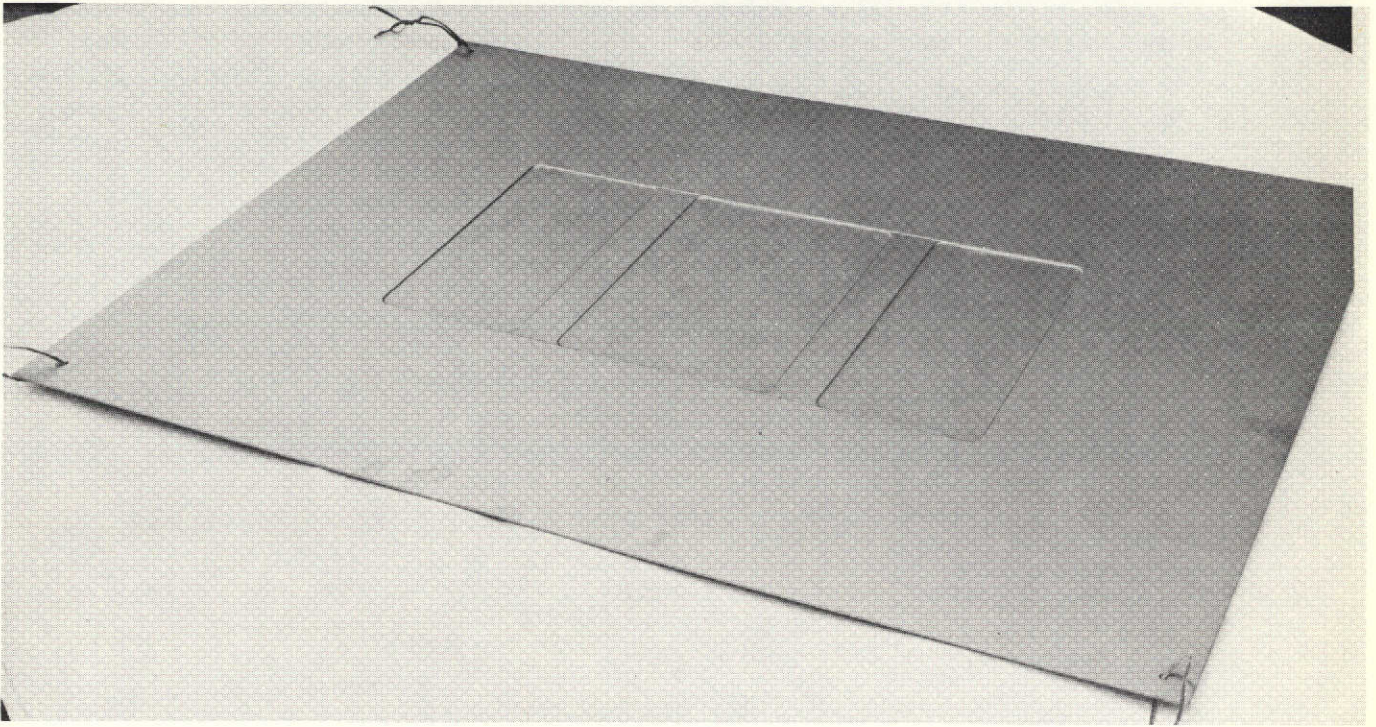


Figure 7: SHEAR WEB TEST ELEMENT - TITANIUM CLADDING SHEET

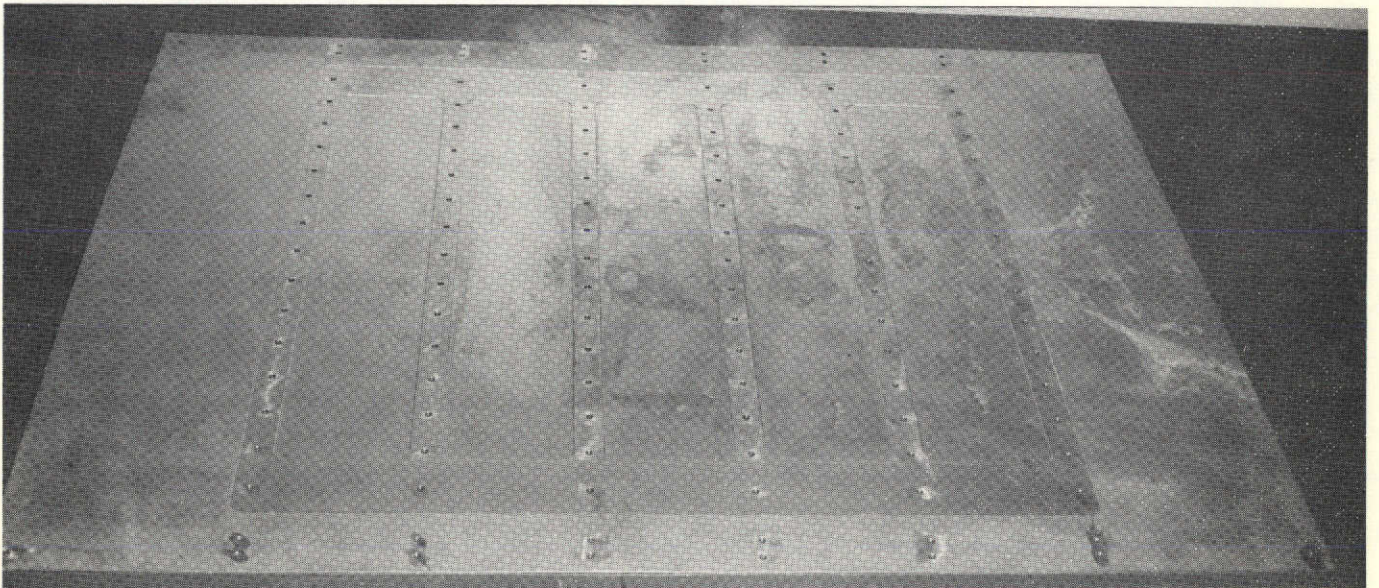


Figure 8: LARGE SCALE SHEAR WEB COMPONENT - TITANIUM CLADDING SHEET

increased to 0.050 in. along stiffener attachment lines to reinforce the cladding in areas with mechanical fastener holes. Extensive Phase I testing was performed to verify the adequacy of the reinforcing lands to reduce strain in the holeout area to acceptable levels.

Drilling tests conducted in Phase I on titanium clad B/E laminate specimens demonstrated that heat build-up caused by drilling through the titanium could cause local delaminations. This delamination problem was eliminated by stack drilling the 0.25 in. stiffener attachment holes into the two cladding sheets prior to assembly bonding (Section 4.4). Additionally, by predrilling the stiffener holes, burrs could be removed before laminating the cladding sheets to the B/E reinforcement.

Prior to final assembly, the cladding skins were cleaned and primed. Reference 2 selected alumina blast with silane rinse as the preferred method for preparing titanium for bonding with Metlbond 329 adhesive. Initially, aluminum oxide abrasive blast cleaning was utilized for all titanium components, including the cladding sheets.

Abrasive blast cleaning gave good results on the step-lap attachment details, but the cladding sheets were slightly warped by the one-sided abrasive blast. This was due to the stress-relieving (shot peening) effect of the blast on one side only. Additionally, the hand process did not lend itself well to the cleaning of large sheets. Consequently, it was decided to use a chemical process with a conversion coating. A phosphate-fluoride metal preparation process was performed in a production shop facility. After the cleaning operation, the cladding sheets were primed with EC-2333 primer and protectively wrapped. The phosphate-fluoride metal preparation process gave good quality assurance for the large scale shear webs.

4.3 Subassembly

Each boron/epoxy reinforcing subassembly was fabricated from a four piece titanium step-lap attachment frame, 8 plies of 5505/4 boron/epoxy prepreg, and one center ply of Metlbond 329 adhesive as shown in Figure 9. Prior to layup of the subassemblies, a prefitting of the cladding sheets and the step lap frame segments was made to assure corner squareness and contact of the step-lap segments and to drill locating holes. Locating holes were stack drilled at each corner and midpoint of each side at the outer edge. These locating holes were utilized throughout subassembly and assembly processes to locate fabrication components.

The layup of boron/epoxy was made on a tool with pins indexed to locating hole positions as shown in Figure 10. This insures that the frame segments will not shift during layup. An aluminum filler was utilized to provide a base for the center ply of adhesive, and the subsequent plies of boron/epoxy prepreg. The 3 in. wide prepreg tapes were then placed edge to edge, with adhesive side down, to generate the required width.

The succeeding plies were layed up according to the desired orientation ($\pm 45^\circ$) until the specified four plies had been applied. A net size ply of nylon peel ply was layed over the 4 boron/epoxy plies to provide a clean faying surface for final assembly bonding.

The half-completed subassembly was flipped over on the locating tool and after pressing the adhesive to achieve intimate contact with the prepreg, the remaining four plies of boron/epoxy were layed in the same manner as the opposite side. A nylon peel ply was placed over the second layup and then was overlayed with a ply of teflon separator film.

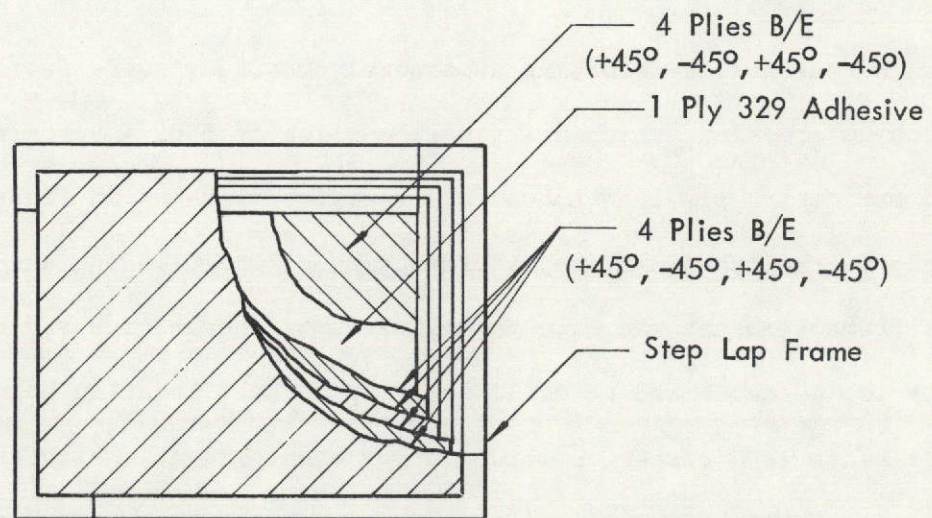


Figure 9: SHEAR WEB SUBASSEMBLY

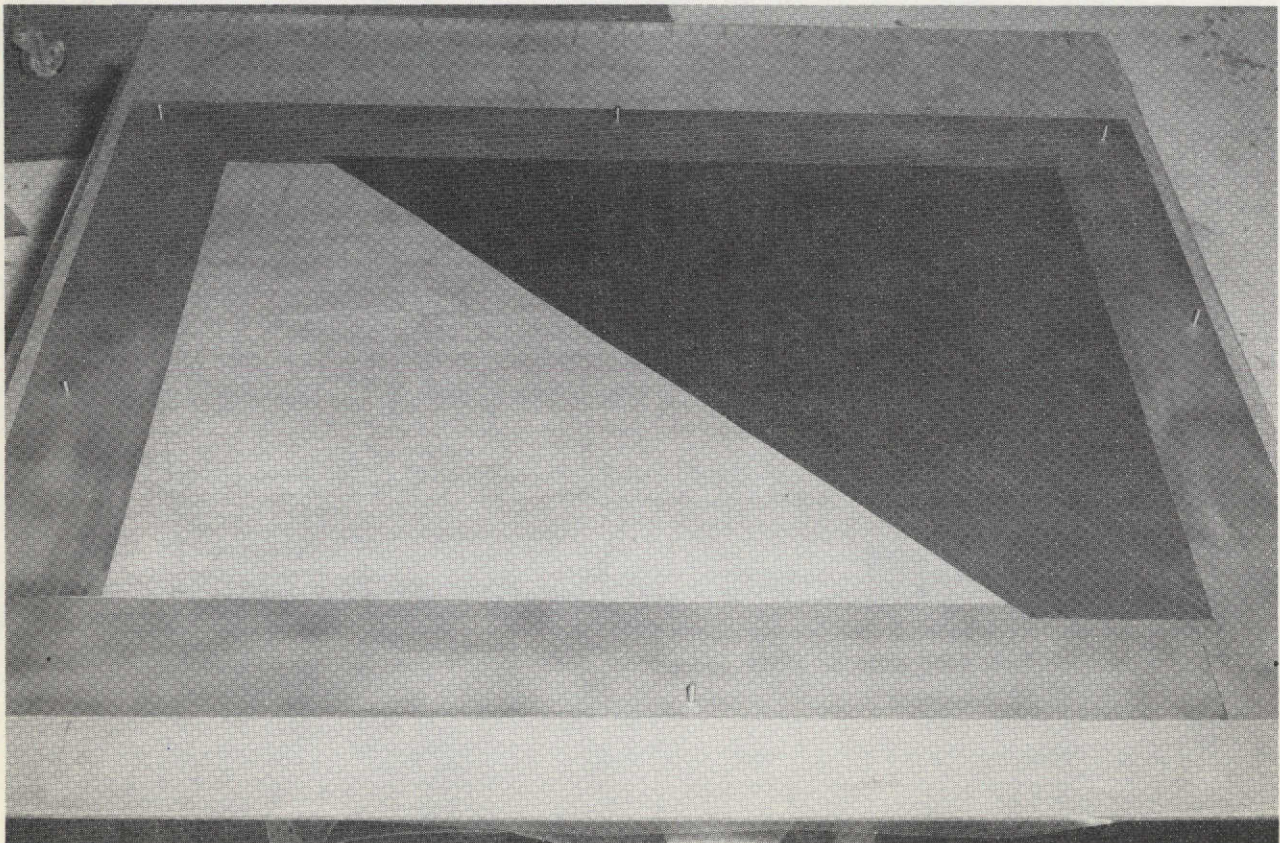


Figure 10: $\pm 45^\circ$ B/E SUBASSEMBLY LAYUP ON LOCATING TOOL

The subassembly was placed on a caul plate and covered with several plies of fiberglass bleeder cloth. A nylon vacuum film covered the subassembly and was sealed to the bonding tool with vacuum sealant tape. The completed subassemblies are shown in Figures 11 and 12. The autoclave cure cycle used in subassembly lamination is shown in Figure 13.

4.4 Assembly

In the final assembly operation of the shear web, the two 8-ply boron/epoxy reinforcing subassemblies and the two titanium cladding skins are bonded together. Three plies of Metlbond 329 adhesive were utilized in the secondary bonding process. Figure 15 illustrates the shear web assembly in exploded view form, and shows the orientation of the assembly components.

The web components were first prefitted without adhesive plies to determine if continuous contact of the mating surface was achieved with finger pressure. Assembly of the web was conducted horizontally on the same locating tool used in subassembly fabrication. The indexing pins position the cladding sheets and the subassemblies with the required accuracy so that a uniform exterior edge was achieved without trimming.

A cleaned and primed cladding sheet was placed on the locating tool, faying surface up, and covered with a net size ply of Metlbond 329 adhesive. Immediately prior to placing the far-side subassembly on the locating tool, the nylon peel ply was removed from both sides. Figure 16 shows the subassembly preparation in progress. This prepared the cured boron/epoxy surface for bonding.

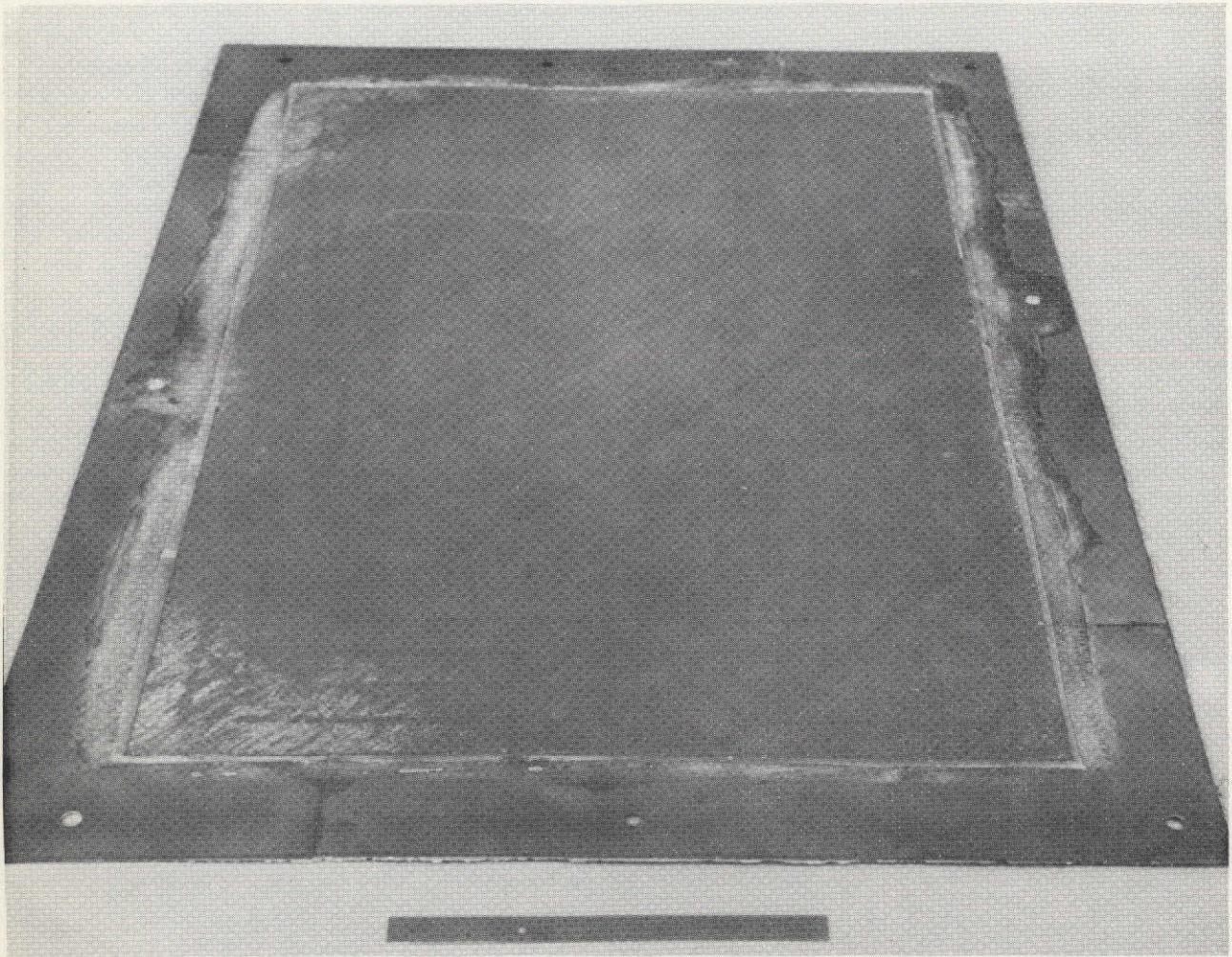


Figure 11: SHEAR WEB TEST ELEMENT - SUBASSEMBLY

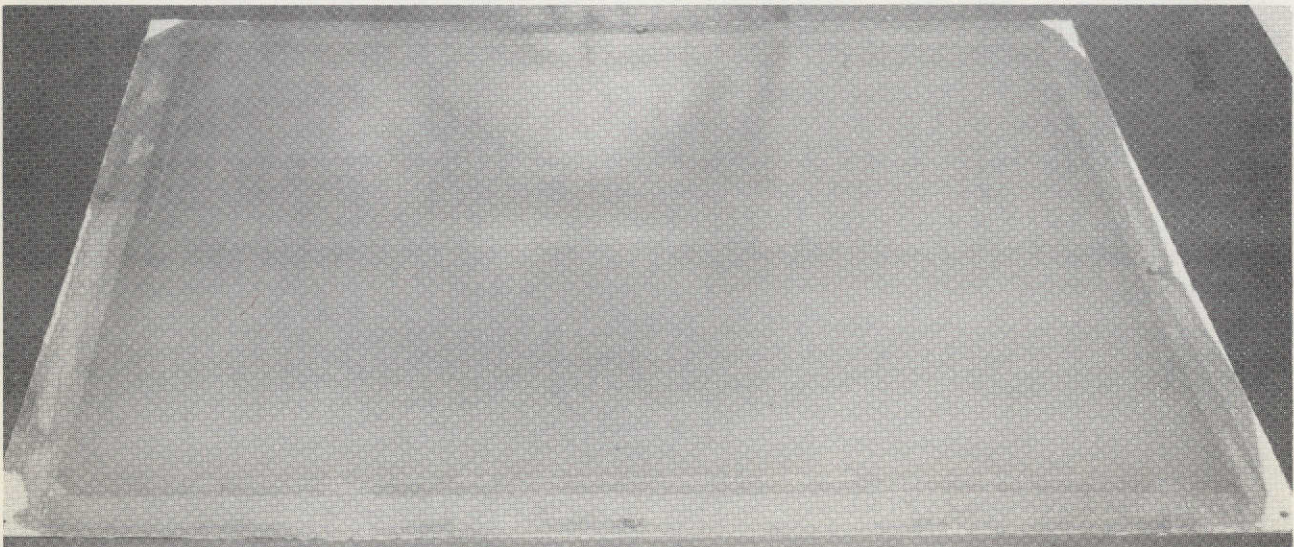


Figure 12: LARGE SCALE SHEAR WEB COMPONENT - SUBASSEMBLY

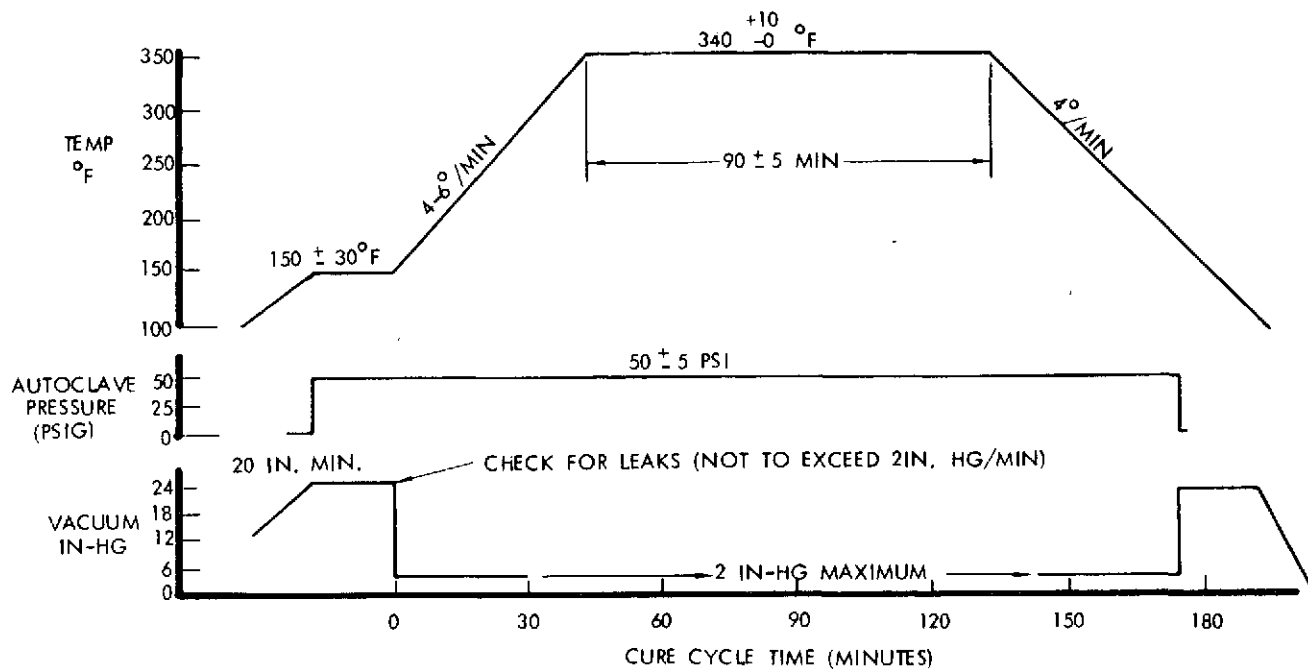


Figure 13: RIGIDITE 5505/4 CURE CYCLE

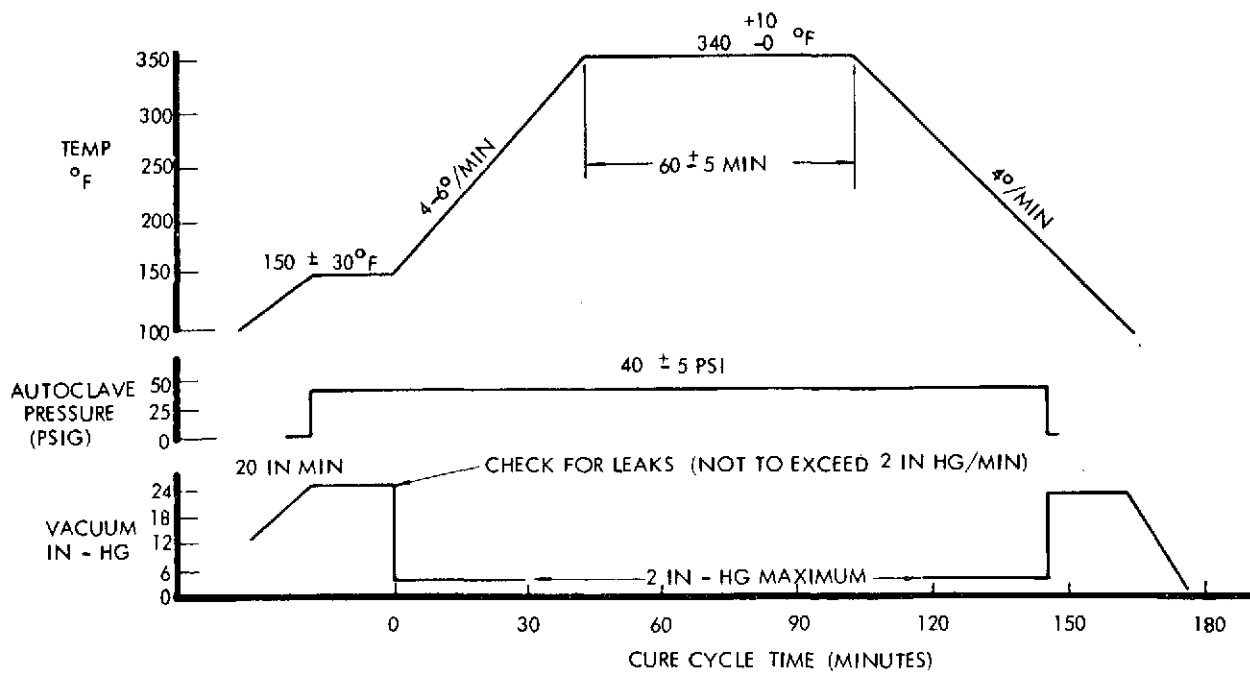


Figure 14 : METLBOND 329 CURE CYCLE

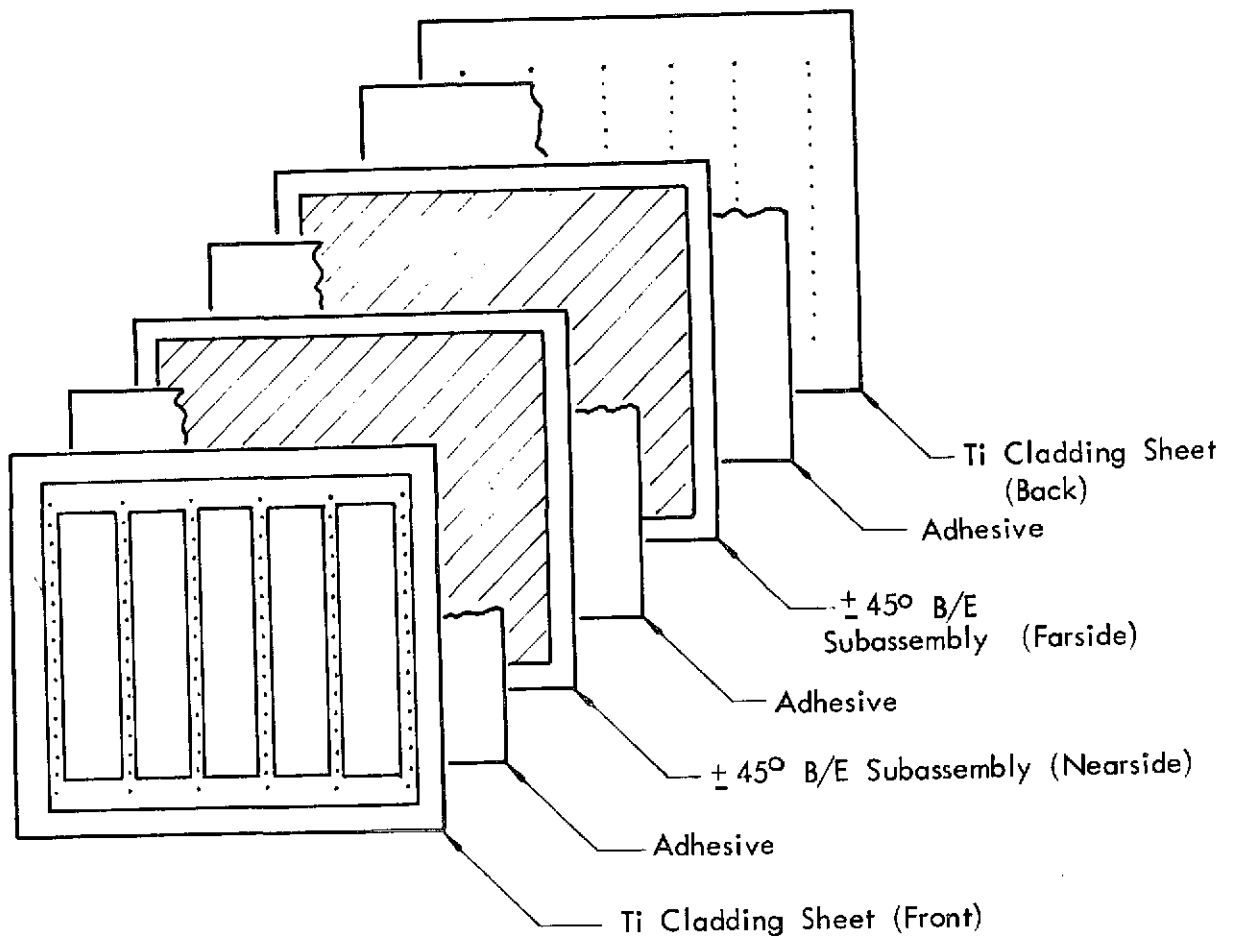


Figure 15: EXPLODED VIEW - SHEAR WEB ASSEMBLY

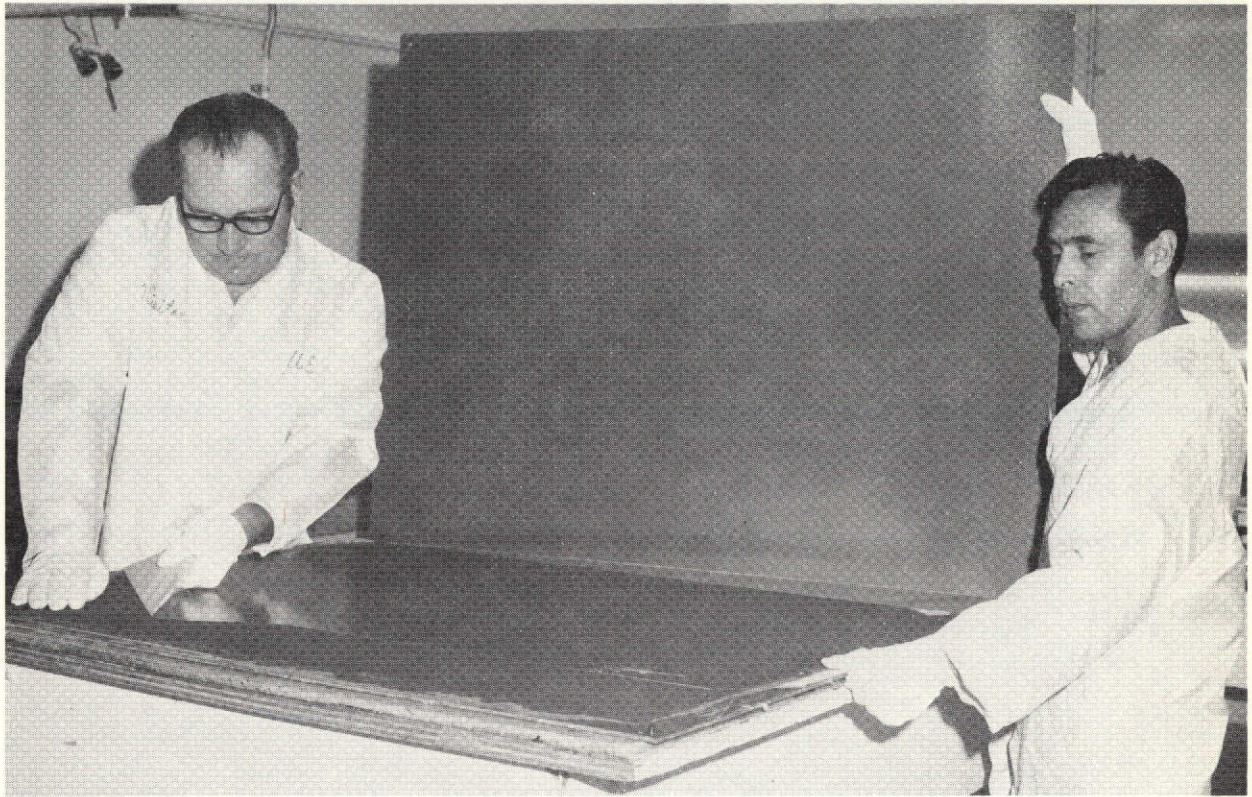


Figure 16: PREPARATION OF SUBASSEMBLY SURFACE FOR ASSEMBLY BONDING

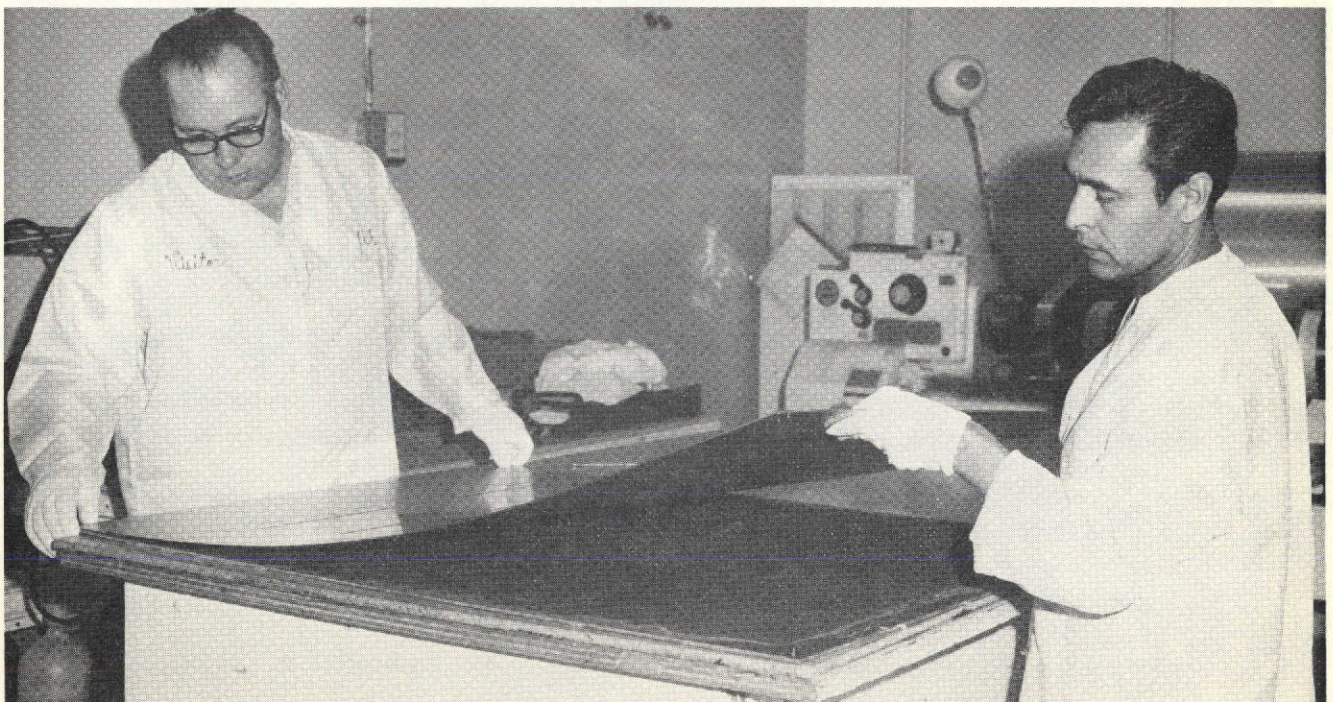


Figure 17: PLACEMENT OF TITANIUM CLADDING SHEET ON ASSEMBLY

The far-side subassembly, after placement on the locating tool, was covered with the second net size ply of adhesive. After removal of the nylon peel plies, the near-side subassembly was then positioned on the locating pins and, in turn, covered with the third net size ply of 329 adhesive. The assembly was completed with the placement of the front cladding sheet, faying surface down, as shown in Figure 17.

Three thermocouples were mounted on the panel surface in order to monitor actual laminate temperatures during cure. The entire assembly was then covered with FEP parting film. One ply of #180 fiberglass and 3 plies of #7500 fiberglass fabric bleeder were placed around the assembly. Care was taken to wrap the glass fabric evenly over the web surface so as to provide an even insulation effect. This minimizes differential thermal gradients over the web surface during the heat-up and cool-down portion of the cure cycle. A nylon vacuum bag encloses the entire web and was sealed with vacuum sealant tape. The bagged assembly is shown in Figure 18. After checking the vacuum bag integrity, the bagged assembly was ready for mounting in the holding fixture. The holding fixture was wrapped with fiberglass cloth to prevent tearing the bagging material. Figure 19 shows the bagged web mounted in the holding tool ready for cure. The web assembly was held in the vertical position during cure. This orientation was utilized in order to insure that no differential thermal effect would occur on the web sides. Had the web been placed on a caul plate, for example, the heat-up and cool-down rates of the web sides would be different. This dissimilar thermal effect would tend to induce panel curvature.

The bagged assembly, after mounting in the holding fixture, was then placed in the autoclave ready for final leak and alignment checks.

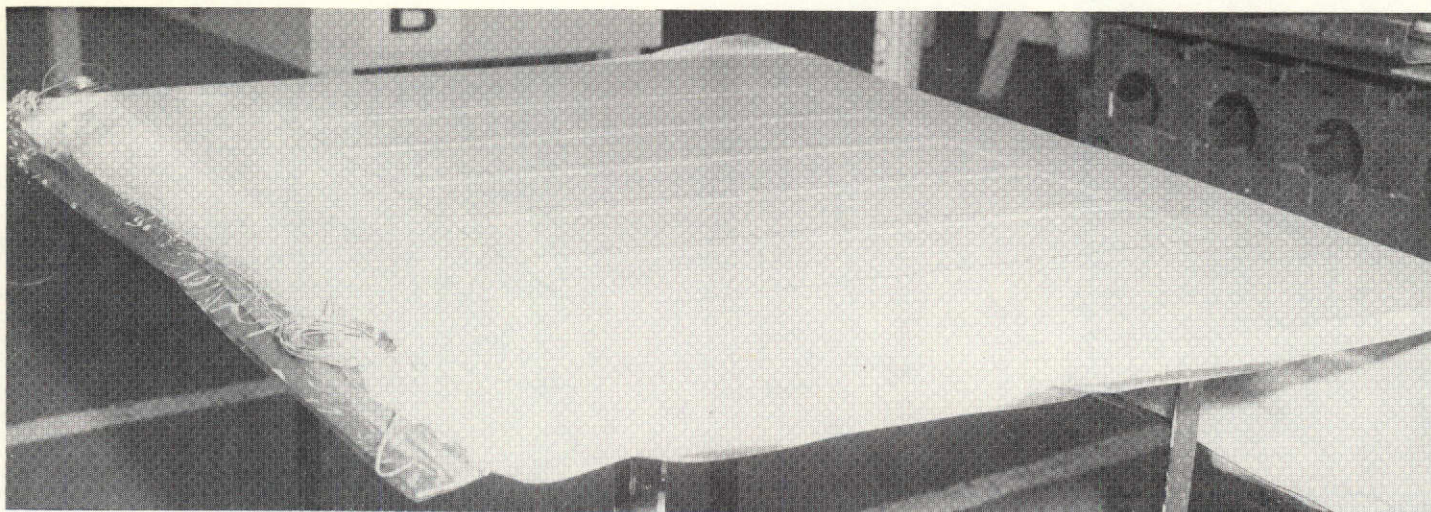


Figure 18 : SHEAR WEB COMPONENT AFTER VACUUM BAGGING

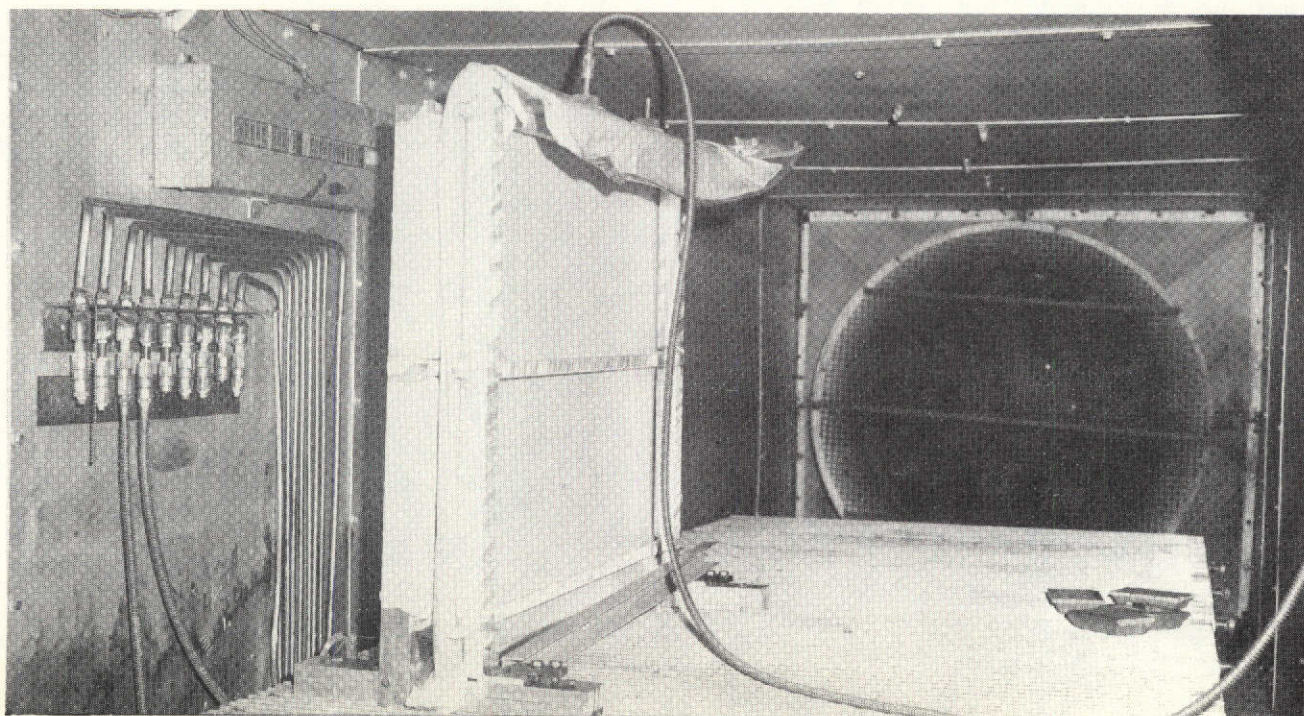


Figure 19 : SHEAR WEB COMPONENT MOUNTED IN HOLDING TOOL

Autoclave curing, following the cycle shown in Figure 14, completes the secondary bonding operation of the shear web assembly. The bonded shear web test element and the large scale test component assembly are shown in Figures 20 and 21. They are detailed in Dwgs. SK2-5085-112 and -117 in Appendix A.

4.5 Finishing Operations

Once the assembly bonding has been completed, the nylon vacuum bag fiberglass bleeder cloth and the FEP parting film are removed from the web. The web was then hand cleaned to remove flashing.

The stiffener attachment holes in the laminate area were predrilled in the cladding sheets prior to assembly as discussed in Section 4.2. High speed steel drills were used after assembly to bore out the B/E reinforcement in the 0.25 in. stiffener attachment holes. No delaminations or other drilling-related problems were experienced.

The shear webs were mechanically fastened to the test fixture (discussed in Section 8.2) by 0.375 in. high strength alloy steel bolts (NAS 1106). An aluminum template was used to match the test fixture attachment hole pattern for subsequent web testing. The periphery attachment holes for shear web component #1 were drilled using the template. However, because of small deformations occurring in the test fixture as a result of web load tests, it was subsequently required to drill the web attachment holes of shear webs #2 and #3 to match in the test frame. Web #3 is shown in Figure 22 mounted in the test fixture after the stiffeners and periphery holes were drilled. The land for the horizontal stiffener used only on shear web #3 is apparent.

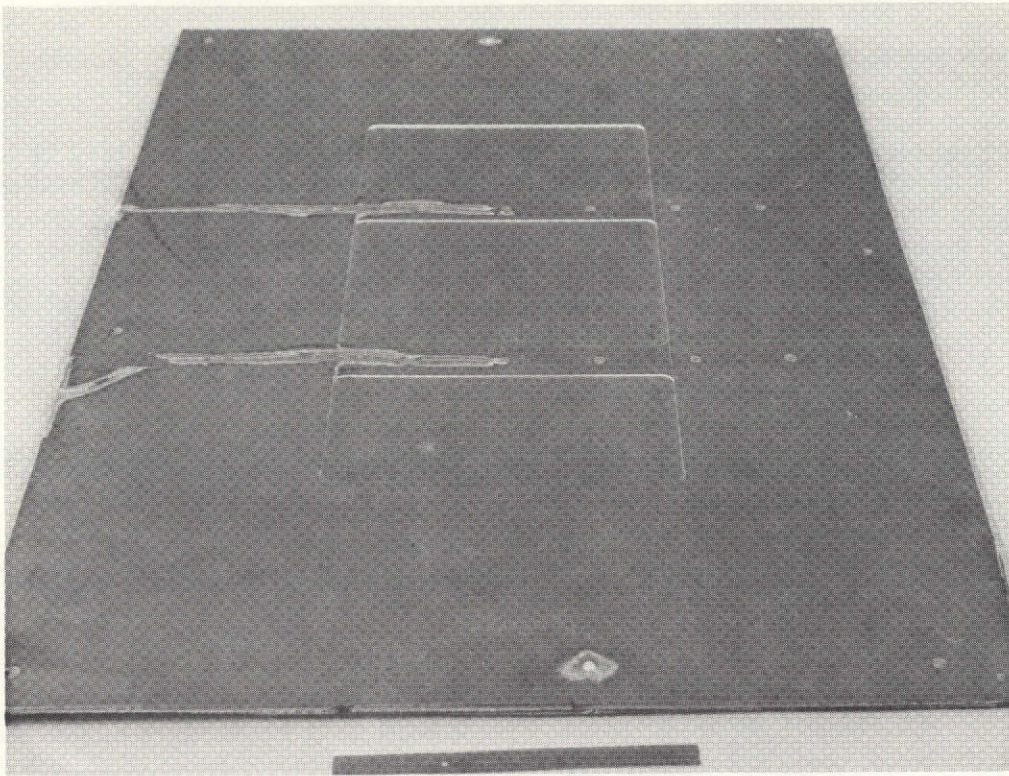


Figure 20: SHEAR WEB TEST ELEMENT - ASSEMBLY

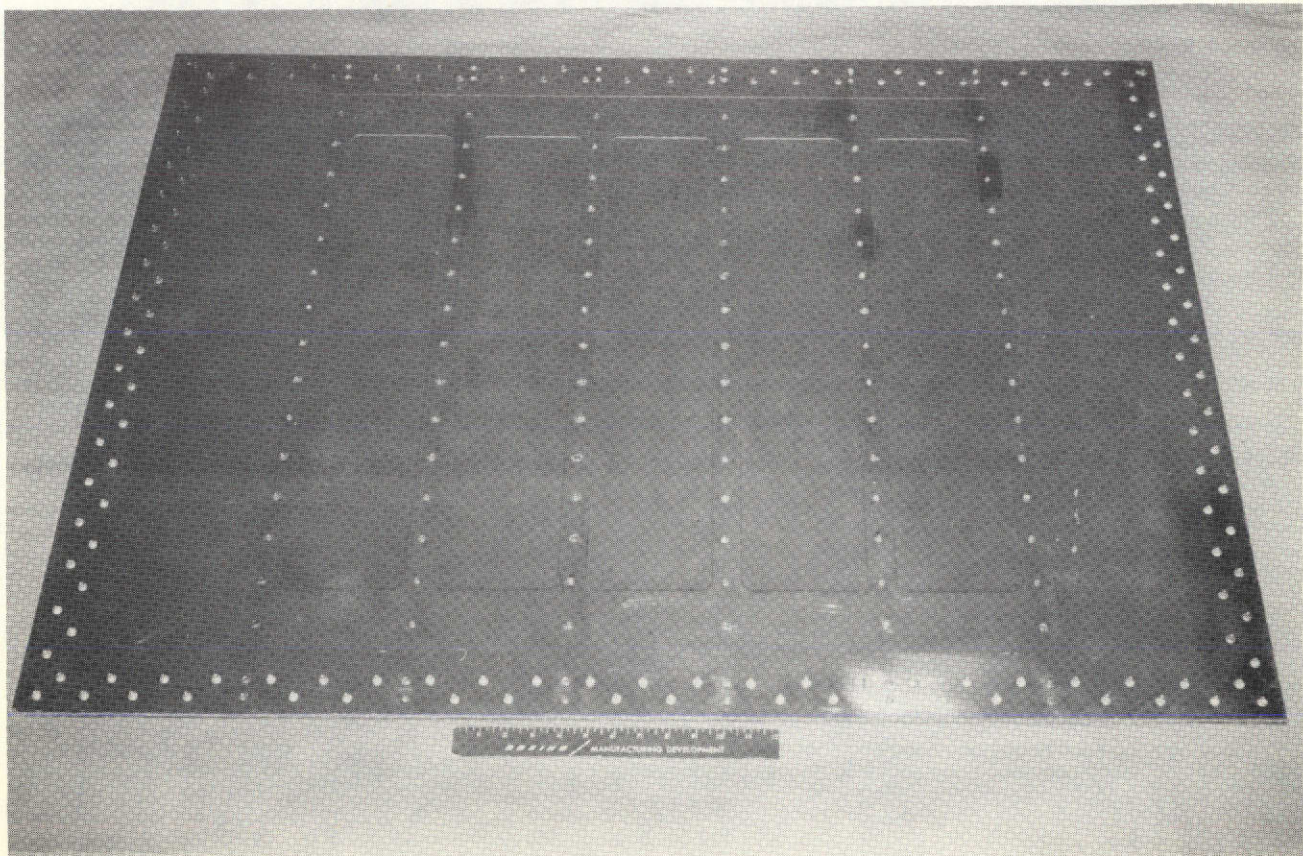


Figure 21 : LARGE SCALE SHEAR WEB COMPONENT - ASSEMBLY

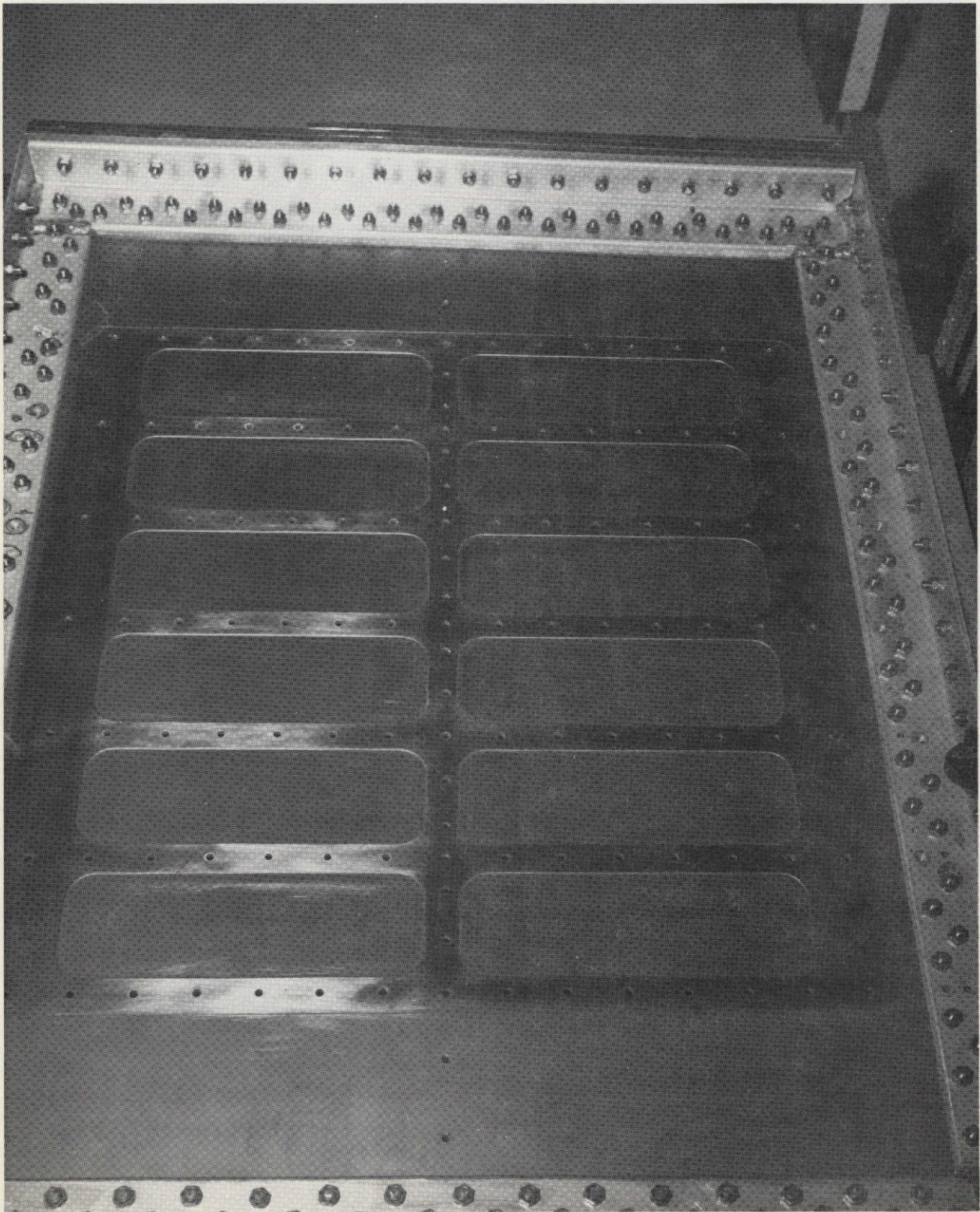


Figure 22: SHEAR WEB #3 WITH STIFFENER ATTACHMENT HOLES DRILLED

4.6 Discussion of Fabrication Processes

The fabrication process utilized for the first of the three large scale (36 in. x 47 in.) shear web test panels (shear web #1) was based on techniques developed on the two 18 in. x 25 in. shear web test elements. Subsequent fabrication of the next two large scale test panels incorporated improvements based on the previous experience.

One intention of Phase II activities was to identify any material and process related anomalies so that they could be considered in the analysis and correlation of test results. One such processing problem was that of repeating nominal panel thickness to the desired tolerance. Even small thickness variations are significant because panel bending stiffnesses are related to the cube of web thickness. Nominal panel thickness differences were noted between the three large scale shear webs.

The design and analysis was based on nominal panel thickness of 0.182 in. as shown.

	<u>Design</u>	<u>Actual (Web #3)</u>
Ti Cladding	0.020 in.	0.018 in.
Adhesive	.012	.010
Subassembly	.053	.050
Adhesive	.012	.010
Subassembly	.053	.050
Adhesive	.012	.010
Ti Cladding	<u>.020</u>	<u>.020</u>
	0.182 in.	0.168 in.

Shear web #3 was fabricated using a new batch of Metlbond 329 adhesive. This batch (Batch No. 407) was measured at 0.011 in. average (0.0104 in. cured thickness) instead of the expected .012 in. cured thickness which was experienced on shear web #1 and #2. Additionally, one of the cladding sheets was

chemical-milled below tolerance to 0.018 in. These combined factors resulted in an average nominal panel thickness of 0.168 in., on shear web #3, as noted above. This reduced the assumed panel bending stiffness by about 25% and cross-sectional area by 8%. The minimum panel measurement was 0.165 in.

Thickness variations can best be controlled by following well defined processing specifications and using a rigid material tolerance system. B/E plies can only be adjusted by incremental ply-sets to maintain a thermally balanced laminate. Small thickness under-runs in subassembly thicknesses were first noted in shear web test component #2. This deficiency was removed by adding another center ply of adhesive in the final assembly bonding operation. This thickness adjustment technique was incremental in ply thickness steps (.012 in.). Additionally, adding an adhesive ply had the drawbacks of adding weight to the panel and creating another bonding interface.

5.0 STIFFENER FABRICATION

The stiffener fabrication process considered the problem of bonding materials of dissimilar thermal expansion characteristics together while maintaining a straight part. This was not entirely achieved, but a considerable reduction in stiffener curvature was made possible by improvements in the fabrication process. The horizontal stiffener utilized on shear web component #3 did not require B/E reinforcement.

The initial stiffener fabrication trial procedure was as briefly outlined below:

- a. Joggle stiffener per design drawing SK2-5085-118 (Appendix A)
- b. Heat treat to T6 (as quenched)
- c. Chemical-mill upper flange thickness to 0.020 in.
- d. Bond pre-cured boron/epoxy reinforcement and .020 in.
aluminum cover sheet to upper flange
- e. Machine upper and lower flange to dimensions per design drawing
SK2-5085-118.

There was considerable difficulty experienced in this early process. Residual stresses distorted the upper flange after step c. was accomplished. Since step d. could not be performed, fabrication was terminated at that time and the development program continued to determine a stiffener fabrication method giving the least resultant curvature. Two initial process verification stiffeners were fabricated to help make this determination. Fabrication sequences for the two stiffeners were as follows:

Specimen 1

- a. Joggle stiffener
- b. Heat treat to T6 (as quenched)
- c. Hand straighten
- d. Bond B/E reinforcement and aluminum cover sheet to upper flange
- e. Machine upper and lower flanges to dimension
- f. Chemical-mill upper flange thickness to 0.020 in.

Specimen 2

- a. Heat treat to T6 (as quenched)
- b. Stretch straighten
- c. Joggle stiffener
- d. Machine to dimension
- e. Bond B/E reinforcement and aluminum cover sheet to upper flange
- f. Chemical-mill upper flange thickness to .020 in.

Process specimen 1 required hand straightening because the joggle in the stiffeners did not permit machine straightening without extensive tooling. Processing for specimen 2 was changed to allow machine stretch straightening. However, the machining operation of step d. produced an unsymmetrical section, and when this operation was performed after heat treating, excessive curvature resulted. This was due to a relieving effect from the residual stresses developed by heat treating. Figure 23 illustrates this effect by showing the resultant curvature of the lower flange after being parted from the stiffener H section. Large scale shear web #1 stiffeners were fabricated by the Specimen 2 sequence with center offset measurements averaging 0.070 in. resulting. The calculated radius of curvature and the center offset was 1487 in. and 0.067 in., respectively.

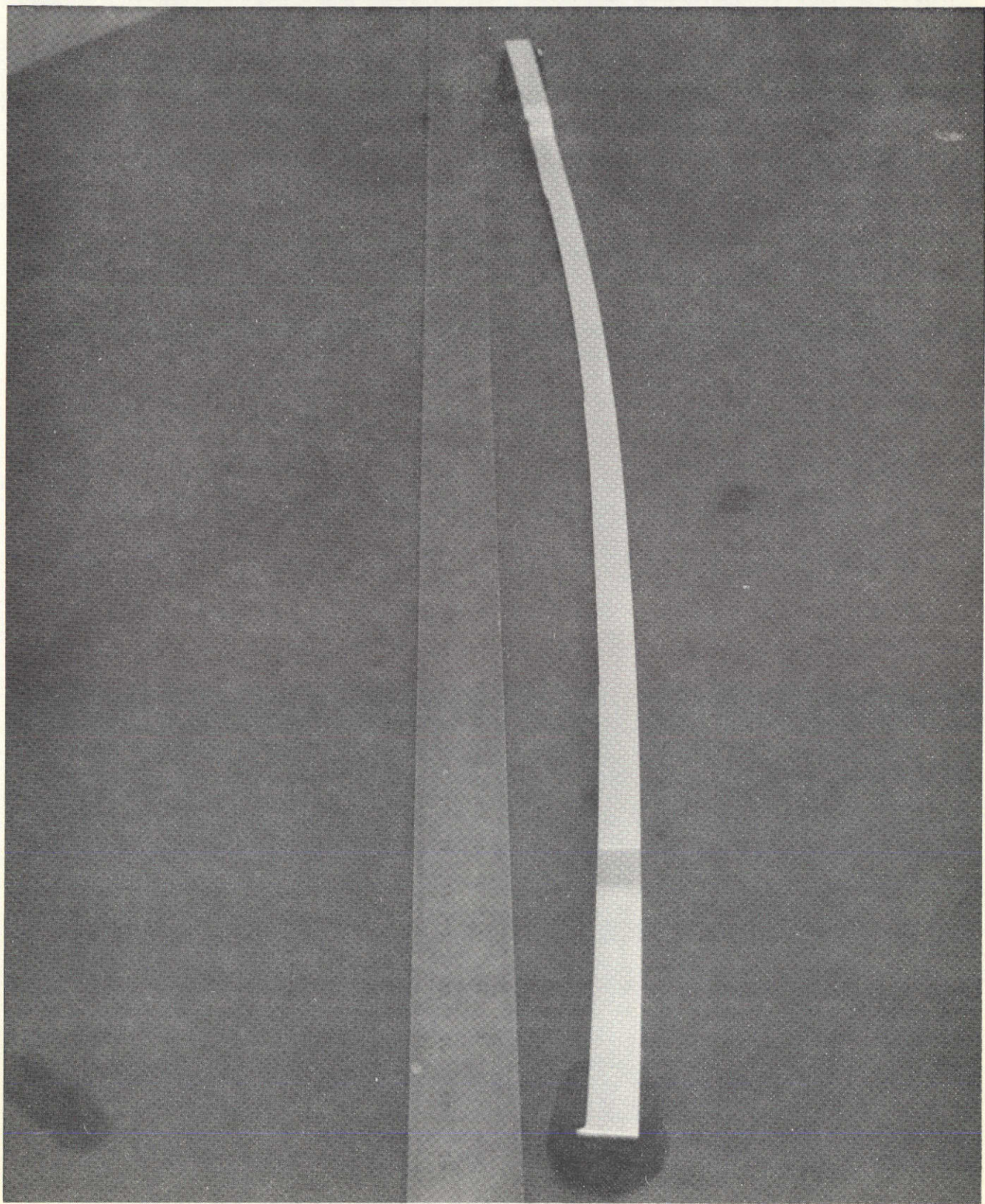


Figure 23 : TRIM STRIP FROM 7075-T6 ALUMINUM STIFFENER

Because distorted stiffeners impose their imperfection onto the shear webs, it was apparent that further improvement was necessary. Process specimen 3 was the next fabrication attempt and followed the sequence shown below.

Specimen 3

- a. Machine to dimension
- b. Heat treat to T6 (as quenched)
- c. Stretch straighten
- d. Joggle stiffener
- e. Bond B/E reinforcement and aluminum cover sheet to upper flange
- f. Chemical-mill upper flange thickness to 0.020 in.

In addition to the fabrication sequence change in specimen 3, another improvement was incorporated into step e. The amount of final residual stiffener curvature was further reduced by restraining the boron/epoxy reinforcement and the aluminum stiffener to deform together during heat-up to cure temperature. In the previously bonding operations, the components shown in Figure 24 would be joined at approximately the cure temperature. Then, when the stiffener cooled to room temperature, the different thermal expansion characteristics of the B/E and the aluminum would cause curvature. By forcing the materials to distort similarly during cure cycle heat-up, however, the stressed condition will exist at cure temperature. As long as intimate contact is maintained between the components, they will bond at cure temperature in the stressed conditions. Stiffener curvature would exist at the cure temperature, but upon cooling, a lessening of curvature results.

Completely stress-free stiffeners at room temperature were not obtained by this prefastening method. The primary reasons for this were in the attachment

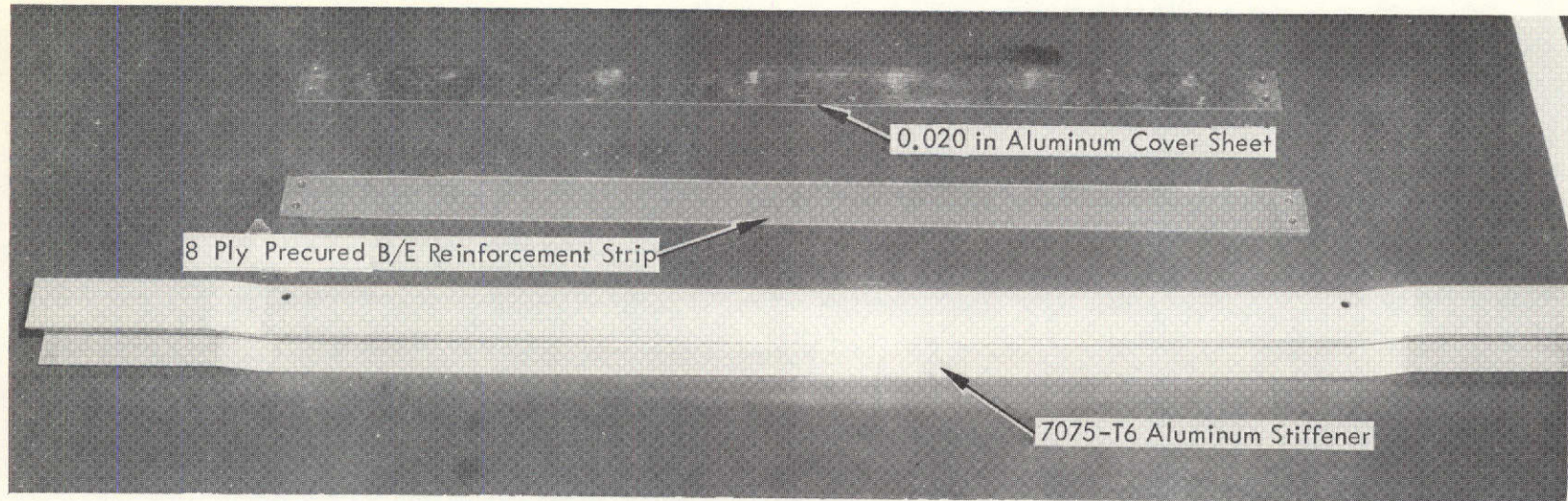


Figure 24: STIFFENER COMPONENTS

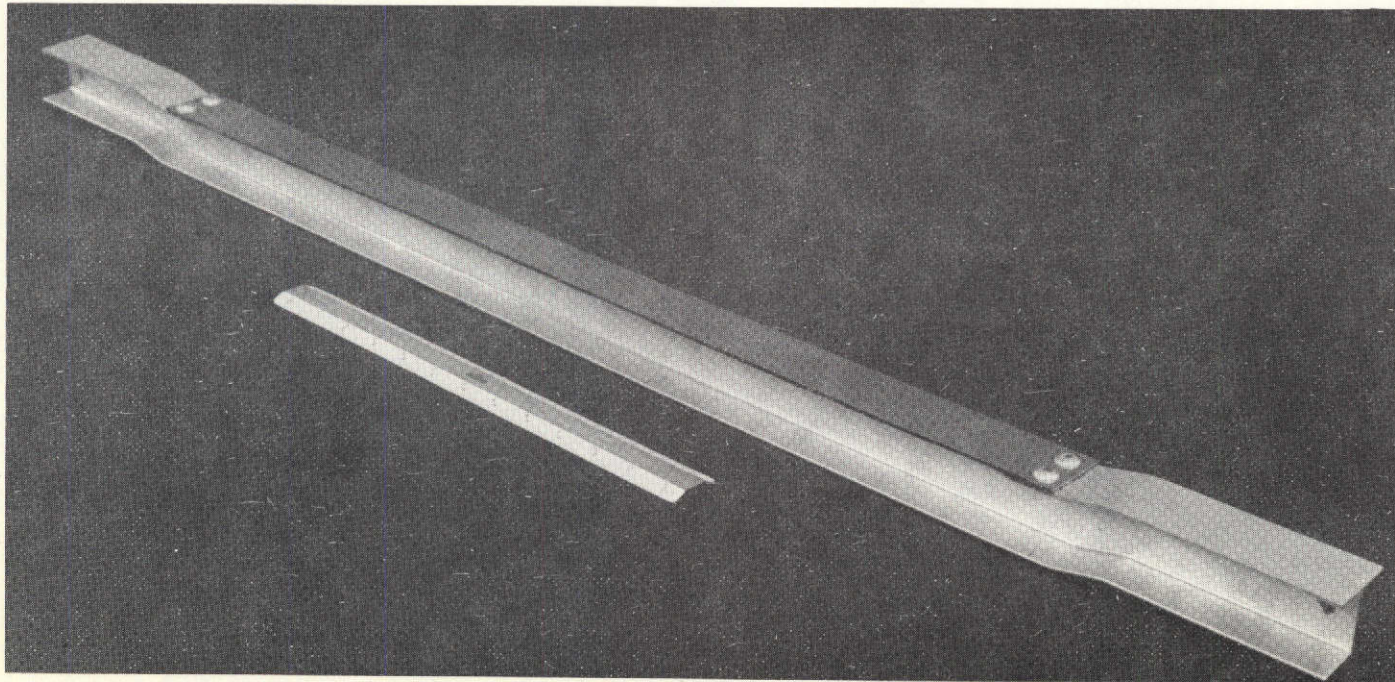


Figure 25: STIFFENER AFTER B/E REINFORCEMENT BONDING OPERATION

technique utilized and the creep deformation of aluminum at cure temperature. The stiffener is mechanically fastened to the reinforcement through the titanium step-lap detail. Fastener hole tolerance was not adequate and the fastening technique itself was not entirely satisfactory. The calculated differential expansion of the two materials is 0.032 in. An 0.005 in. joint slippage at each end of the boron/epoxy reinforcement is entirely feasible. With a total slippage of 0.010 in. then, the radius of curvature of the stiffener at room temperature would be 2,040 in. This relates to a center offset of 0.048 in. The stiffeners on shear web #3 had measured center offsets of 0.050 in. average. This would indicate that a close tolerance (Class 1 or better) fastener is required. Figure 25 shows the stiffener after the B/E reinforcement bonding operation.

The stiffeners of shear web components #2 and #3 utilized the fabrication sequence of stiffener specimen 3. Figure 26 diagrams the stiffener fabrication flow as adopted for the stiffeners of the last two large scale shear webs.

The assembly of the stiffeners to the web is the final fabrication step. However, stiffeners with curvature tend to distort the plane of the web to conform to that curvature, as discussed earlier. These out-of-plane deflections serve as initial imperfections which greatly reduce the shear resistant behavior of the web under load. It was considered that a ± 0.005 in. straightness tolerance for the stiffener was required to prevent excessive initial imperfections from being introduced into the web plate.

The required ± 0.005 in. tolerance was achieved on web #2 and web #3 by shimming with the epoxy potting resin. On shear web #2, the epoxy shim was potted to the stiffener on a flat table. This proved unsatisfactory, however, because of the web thickness taper in step-lap frame transition area.

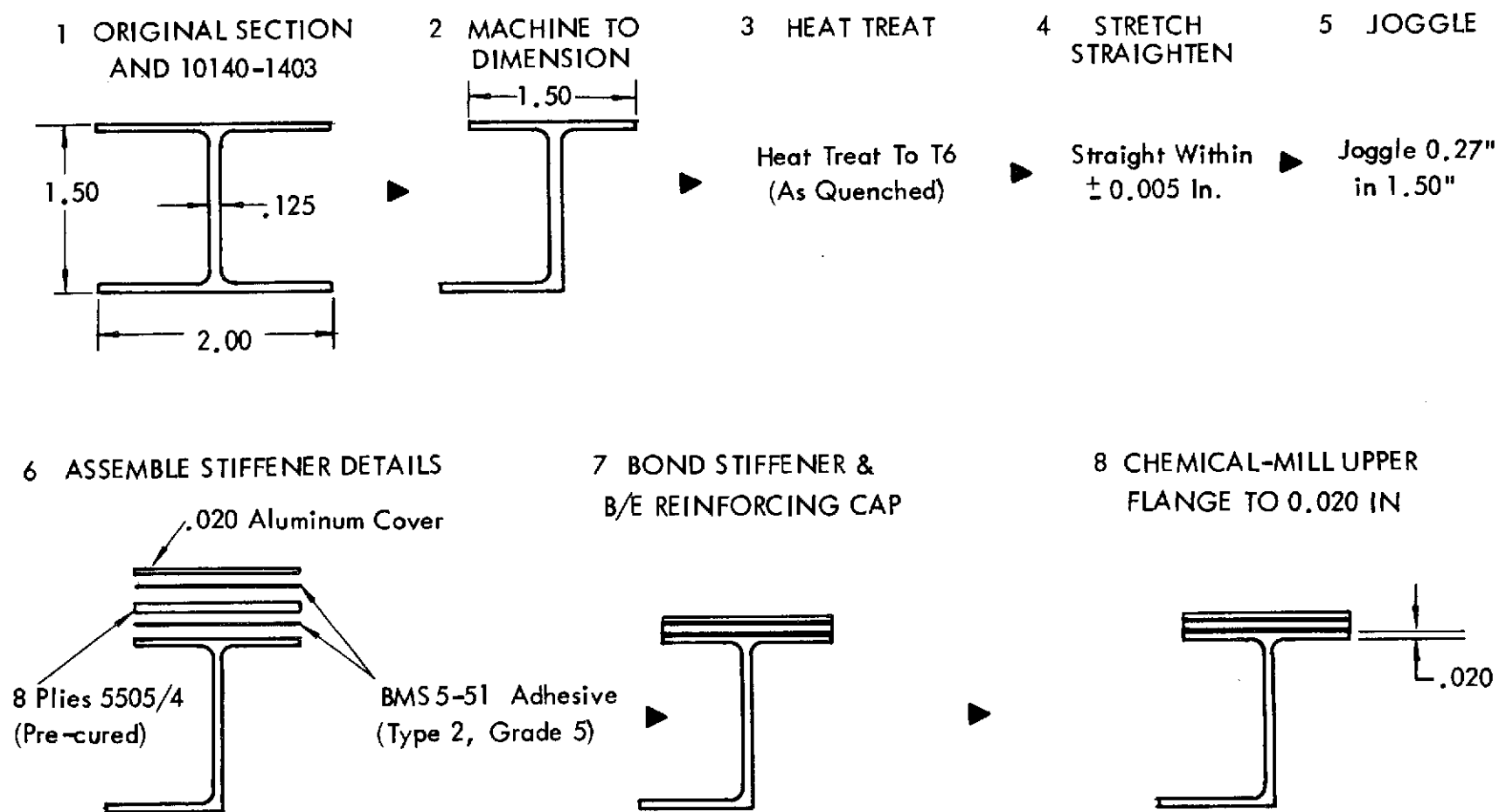


Figure 26: STIFFENER FABRICATION FLOW DIAGRAM

(Dwg SK2-5085-118 Reference)

The perfectly flat stiffener foot did not conform to the small surface undulations and tended to pull the web out of plane. Section 4.1 discusses the web thickness reduction problems in the titanium/B/E transition area and its solution for shear web #3.

The epoxy potting of shear web #3 stiffeners was performed on the web itself. This allowed this shim to eliminate the effect of small web surface perturbations which occurred on the basically flat webs. Additionally, the thickness taper in the step-lap frame area was significantly reduced from that of shear web #2. While this approach to reducing the effect of stiffeners on the plane of the web was not considered suitable for a production process, the design and test conditions of this program were satisfied.

6.0 WEIGHTS

Component weights were recorded at various stages of fabrication of the shear webs. Typical values are reported in Table 3. Accurate weight predictions can be developed for design changes using the data shown. For example, adding 1 ply set (8 plies boron/epoxy) would add 9.84 lbs. to the total web weight. (1 subassembly of 8.72 lbs + 1 ply adhesive of 1.12 lbs.)

The web total estimated weight (with 7 stiffeners) is 58.21 lbs. which compares well with the average actual weight of 58.36 lbs.

TABLE 3: WEB WEIGHT SUMMARY

<u>Item</u>	<u>Qty.</u>	<u>Weight</u>
<u>B/E Subassembly</u>		
Titanium step-lap frame	1	3.95
Boron/epoxy prepreg	8 plies	4.05
Adhesive (Metlbond 329)	1 ply	<u>.72</u>
Total Subassembly Weight		8.72 lb (9.05 lb Actual)
<u>Web Assembly</u>		
B/E Subassembly	2	17.44
Adhesive (Metlbond 329)	3	3.36
Titanium cladding sheets	2	<u>24.18</u>
Total Web Weight		44.98 lb (44.6 lb Actual)
<u>Stiffeners</u>		
Aluminum J Section	1	1.65
Titanium step-lap details	2	.02
B/E reinforcement	8 plies	.14
Adhesive (BMS 5-51)	2 plies	.02
Aluminum cover	1	<u>.06</u>
Total Stiffener Weight		1.89 lb (1.83 lb Actual)
Total Stiffened Web = 58.21 lb (58.36 lb Actual) (7 Stiffeners)		

7.0 IN-PROCESS QUALITY CONTROL

Quality Control verification of the integrity of shear web components consisted of destructive and non-destructive tests. Manufacturer's letters of conformance and inspection reports were utilized for materials-receiving certification for the boron/epoxy prepreg. Strict adherence to environmental storage requirements was maintained and a usage log recording time at other than storage temperature for the B/E and the adhesive was kept. Storage temperature was held constant at 0°F.

The main element in the quality control program for a fabrication process such as that reported in this document is that of assurance that interface surfaces, of similar and dissimilar materials, have an adequate bond.

Probably the most critical part of advanced composite fabrication is that of workmanship. Tape-laying machine setup is costly and restricted to relatively simple lay-ups. Although the shear web concept considered here was amenable to automatic tape-laying, it was decided because of limited production to utilize hand lay-up. Therefore, it was important that much of the in-process controls were implemented into the fabrication flow at frequent points. Inspection buy-offs were performed by engineering or designated shop leaders.

The cladding sheets were chemically cleaned and a phosphate-fluoride conversion coating was applied as described in Section 4.2. This was performed in a production shop following certified procedures. The cladding sheets were

immediately primed to protect the clean surface. Completeness of the primer coverage was quantitatively assessed by reflected light observation.

Prior to the final assembly bonding operation, a complete visual inspection of all components was made. This bonding operation requires non-destructive testing to verify the quality of the bond between the titanium and the boron/epoxy subassembly. Two techniques were utilized; radiographic inspection and ultrasonic inspection. No failure in any of the test coupons, specimens or shear web test elements were attributed to bonding defects.

7.1 Radiographic Inspection

Radiographic inspection was performed on a Norelco MG 150 radiation source with 150 KVP capability. Conventional radiographic techniques and films were utilized. The radiographic inspection was used to detect discontinuities in the laminate. X-rays were made of the entire shear web panel to indicate the uniformity of lay-up (i.e., to reveal inclusions or voids in the laminate). However, these films would not detect areas of insufficient bond between surfaces.

Figure 27 shows a typical x-ray of a section of shear web #1. Orientation of the film with the web is shown. A small inclusion was noted in the x-ray films and is shown in the figure. An autopsy was performed on the defect area after testing and a small clump of fiberglass scrim cloth was discovered to be the cause of this flaw. This caused the cladding sheet to ride over the bump and leave an unbonded pocket as shown in the sketch below. This void area was slightly depressed and larger than what would be expected, probably due to gas collection of adhesive outgassing in the pocket.

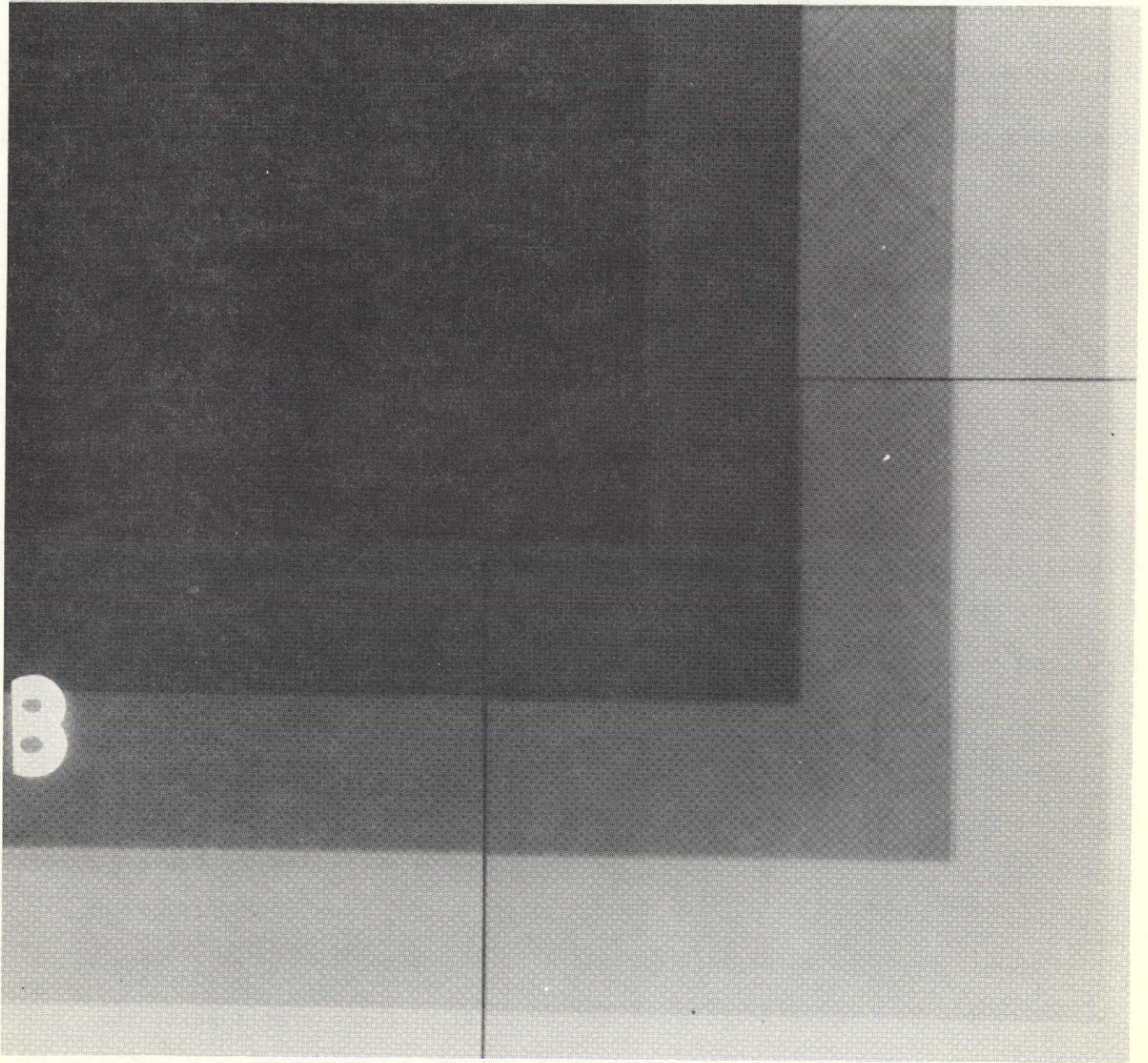
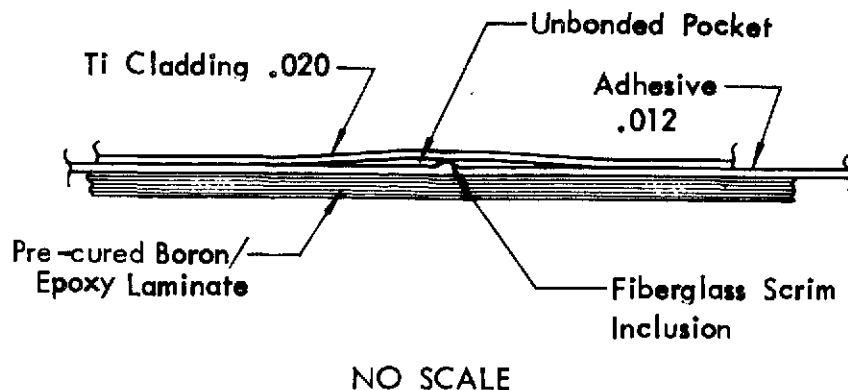


Figure 27 : SHEAR WEB #1 CORNER X-RAY



The web corners were also identified as areas of concern. Consequently, x-rays were taken of the step-lap frame staggered butt joints in these areas. Figure 28 shows a typical corner detail of shear web #1. The steps of the titanium transition fitting are clearly evident.

7.2 Ultrasonic Inspection

Ultrasonic inspection was conducted with an Immerscope 725 Pulser-Receiver. A 1 MHz through transmission technique was utilized with 0.25 in. water jets to couple sound. The scanning pattern was vertical with 0.057 in. horizontal saw-tooth indexing. Facsimile recording was synchronized with the water jet scan to prepare a C-scan recording of sound attenuation through the test part.

Figure 29 shows a full panel tracer sheet of shear web #2. An apparent 4 in. diameter area of partial bonding was detected by the test. The resolution of the inspection is shown by the clarity of the step-laps of the titanium attachment frame.

The defect area discovered by x-ray examination of shear web #1 was subjected to ultrasonic examination with an Automation Industries UM721

Pulser-Receiver set at 5 MHz through transmission. Sound was coupled through 0.25 in. water jets which scanned horizontally. The tracing shown in Figure 30 indicated that there were two small defect areas on the web. Neither defect was considered large enough to pose a problem in test loadings. However, since defect number 1 had a smooth 0.013 in. surface protrusion, it was decided to monitor the area closely during the testing of the web. This was the same defect discussed in Section 7.1.

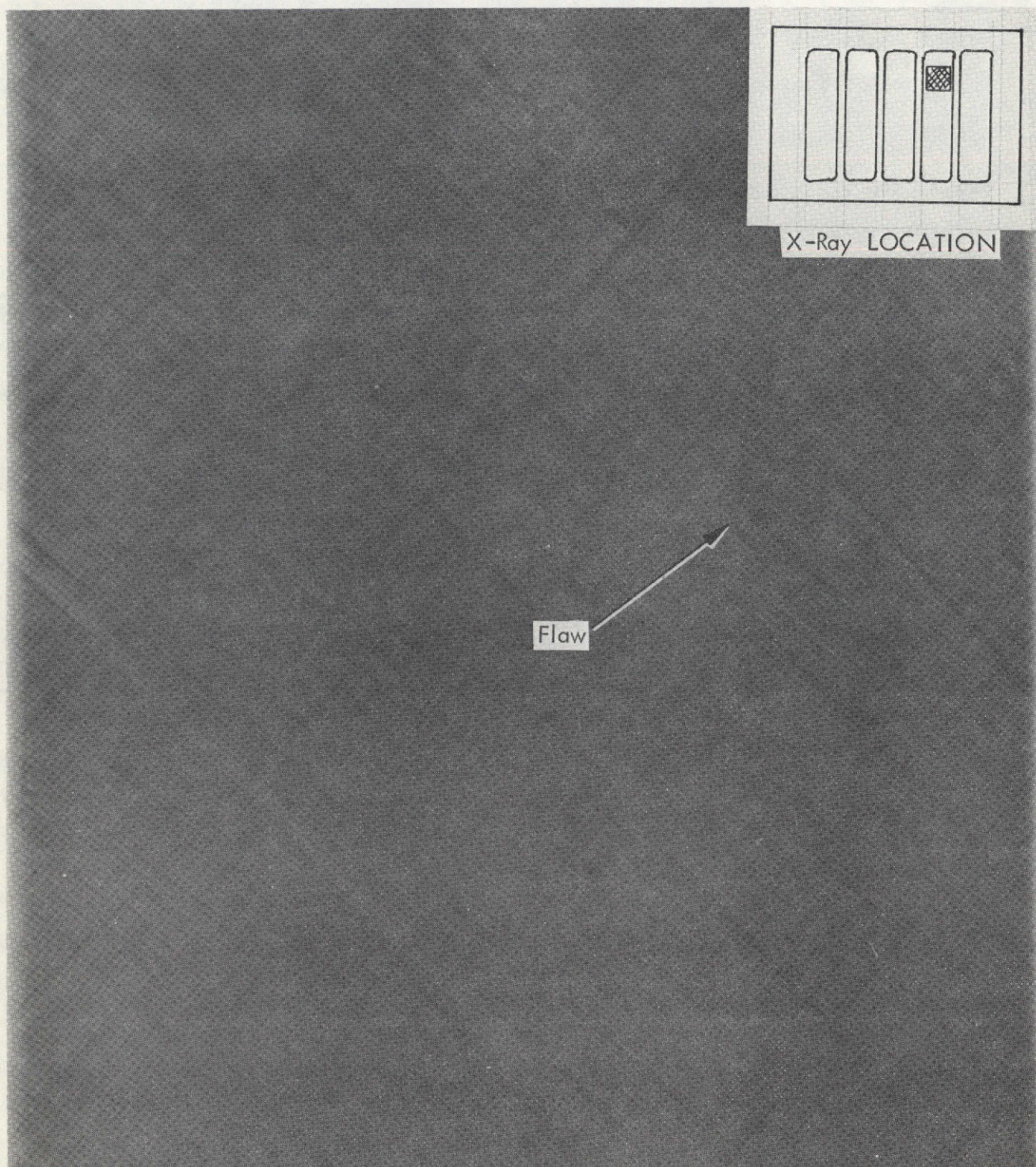


Figure 28 : SHEAR WEB #1 X-RAY

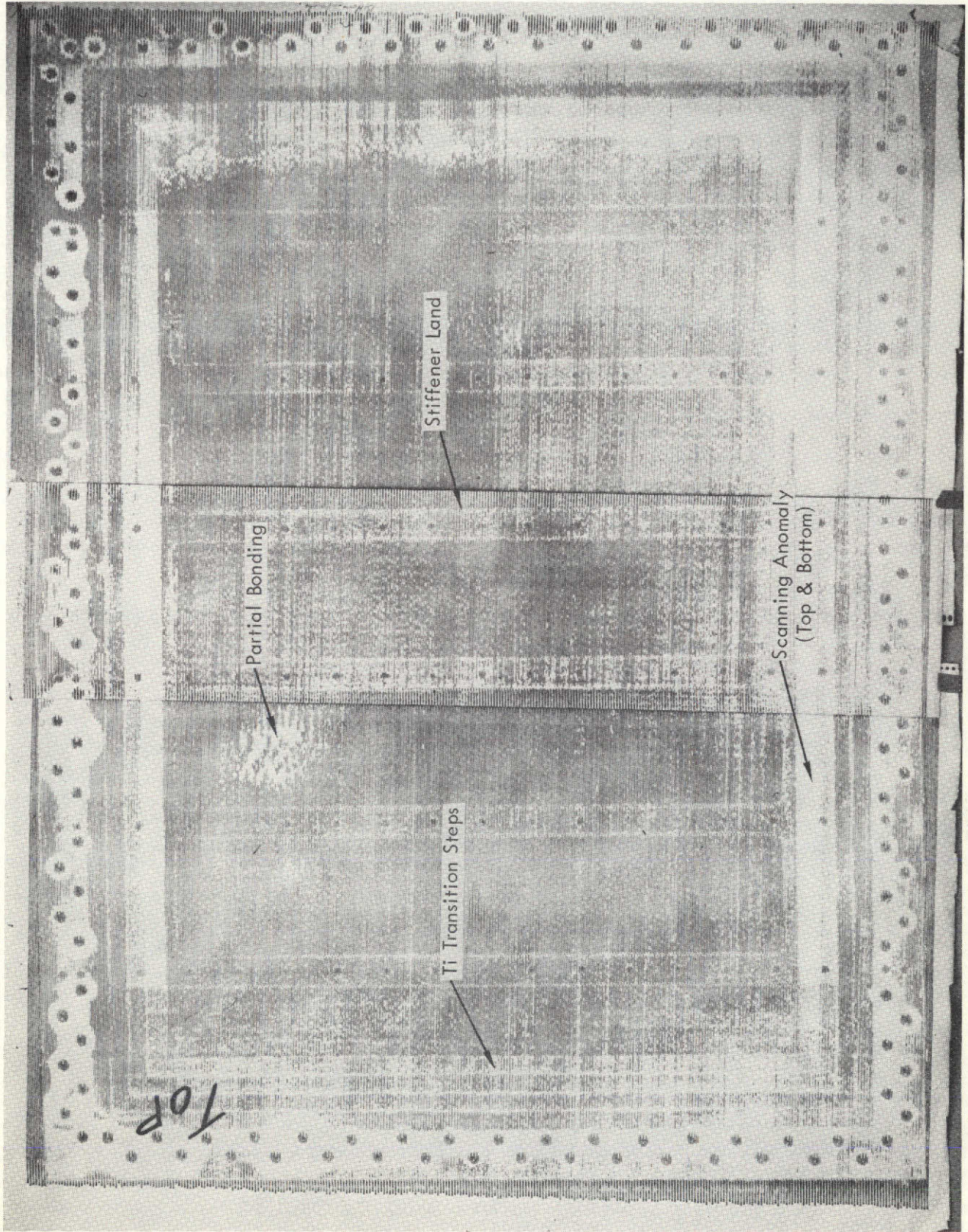


Figure 29: SHEAR WEB #2 ULTRA-SONIC INSPECTION RECORDING

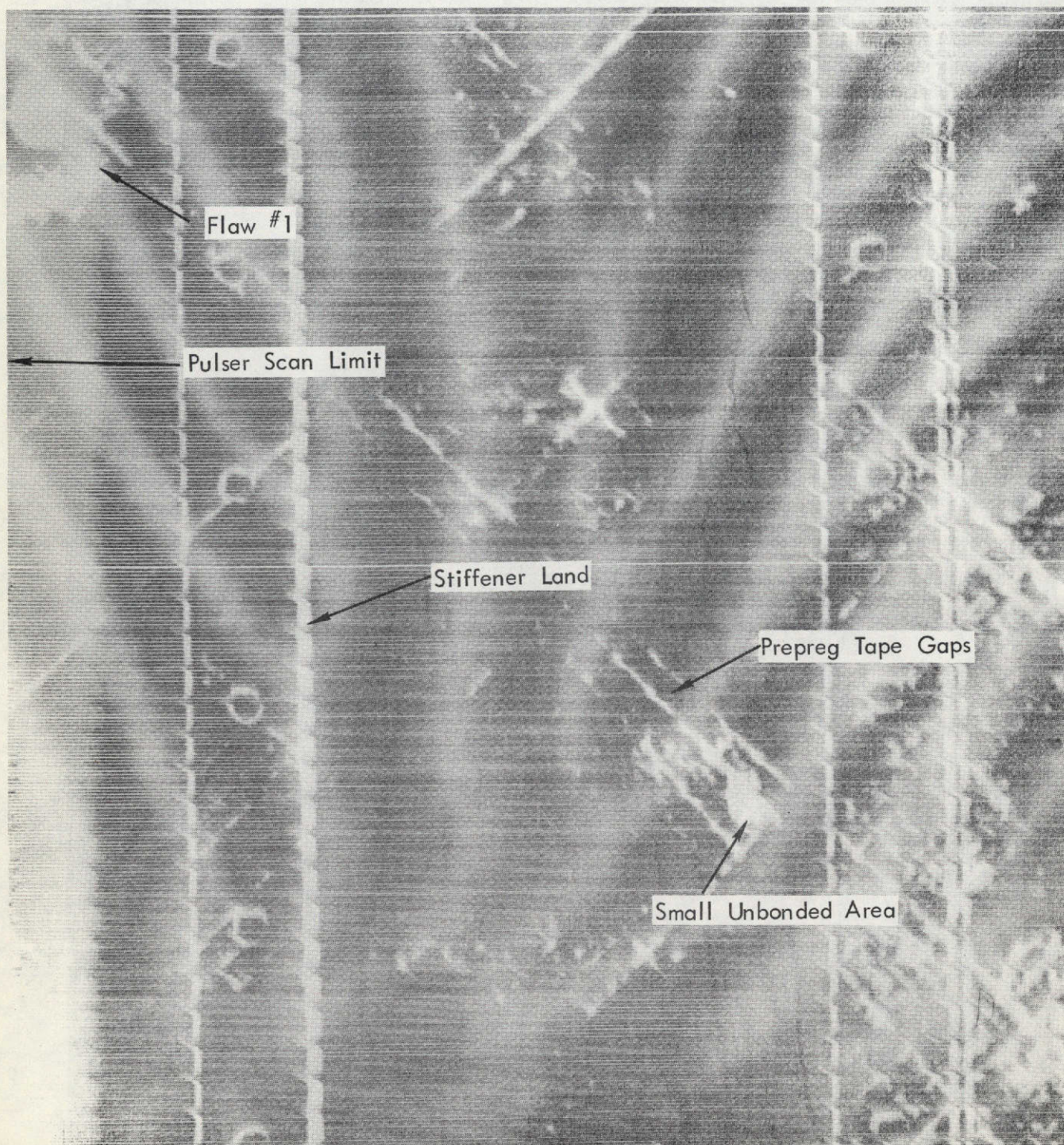


Figure 30: SHEAR WEB #1 ULTRA-SONIC RECORDING

8.0 TOOLING AND TEST FIXTURES

One of the more significant benefits of the selected shear web design concept is its ease of fabrication and its minimal tooling requirements. The required fabrication tooling was free from manufacturing complexity and easy to use.

8.1 Tooling

The layup of the subassemblies was performed on a simple loading tool which had pins that indexed the step-lap frame segments to each other. Figure 3 of Section 4.1 shows the pins locating the frame. The indexing holes were stack-drilled into the titanium frame and cladding skins.

After assembly and vacuum bagging, the web is placed in a vertical position in the holding fixture as discussed in Section 4.4. The tool is shown in Figure 31. The fixture was constructed of small gage aluminum channels and angles. Center braces were added after web #1 was fabricated to improve flatness.

8.2 Test Fixture

Two test fixtures were designed and fabricated. Figure 32 shows the test fixture for shear web test element testing. The three large scale shear webs required the test fixture shown in Figure 33. The fixtures were designed as simply supported beams with a central load. The test webs were inserted into the frame formed by the beam flanges and the center and edge posts, and mechanically fastened. The dummy side of both test fixtures was fabricated from 0.25 in. aluminum plate and was a permanent part of the fixtures.

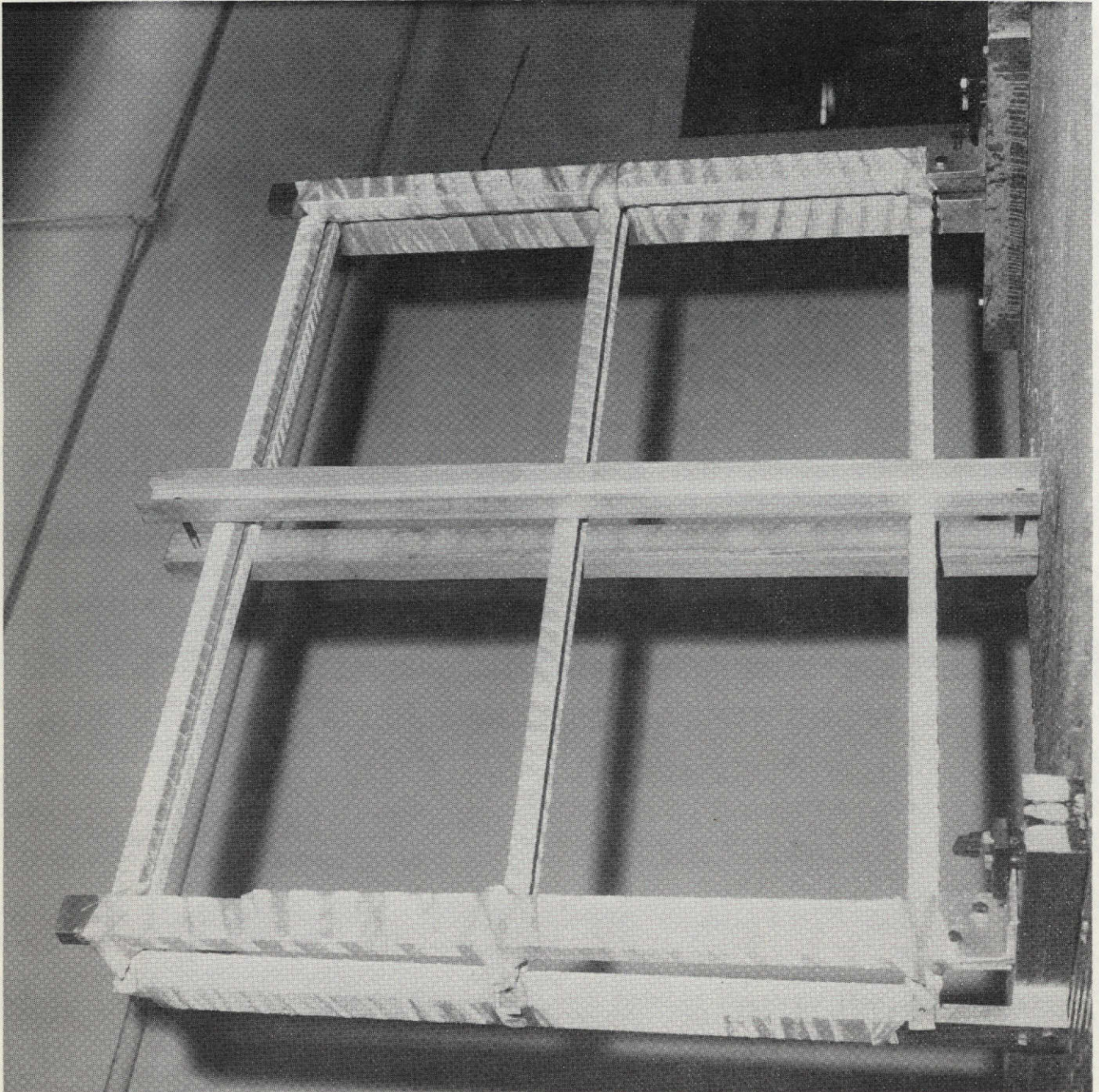


Figure 31 : SHEAR WEB COMPONENT AUTOCLAVE BONDING TOOL

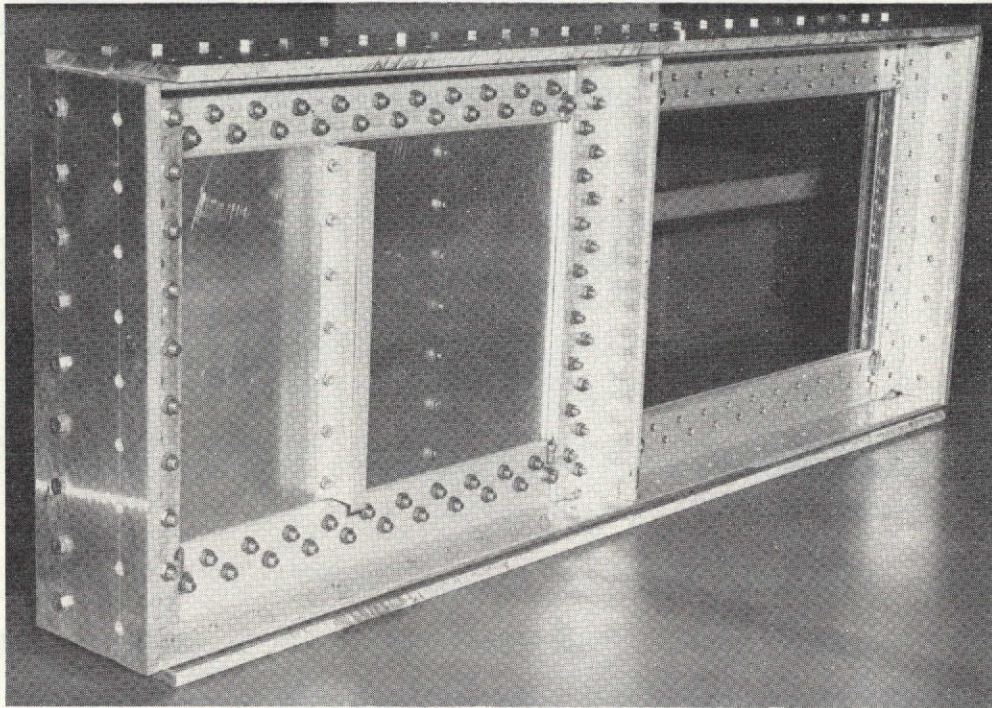


Figure 32: SHEAR WEB ELEMENT TEST FIXTURE

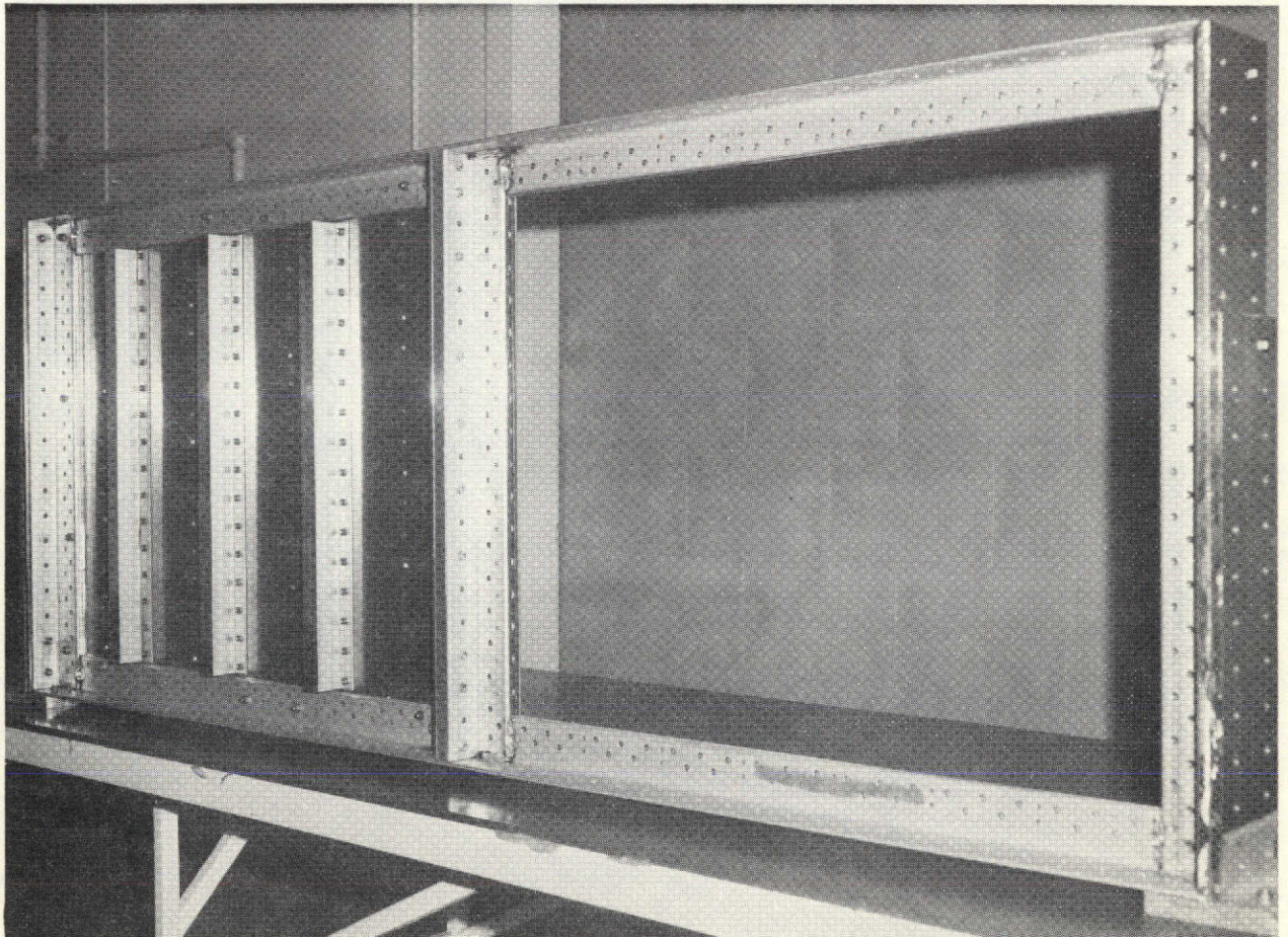


Figure 33: LARGE SCALE SHEAR WEB COMPONENT TEST FIXTURE

The large scale shear web test components were attached to the aluminum vertical angles and the aluminum horizontal chords with 0.375 in. bolts. Drawing SK2-5085-114 shows the details of the test fixture. SK2-5085-113 details the test fixture for testing the two 18 in. x 25 in. shear web test elements. Both drawings are in Appendix A.

The stiffeners of the shear web test components were joggled to ride up over the chords. They were mechanically fastened to the chords to provide support for the stiffener ends. Figure 34 shows the stiffener joggle although the 0.25 in. alloy steel (NAS 1104) bolts had not yet been installed when the photograph was taken. The one inch thick aluminum load pad is evident also. The test fixture is upside down in the photograph.

Shear web #2 with stiffener installed is shown in Figure 35 mounted in the large scale component test fixture. The panel has been strain gaged and is ready for testing. Small clips at the top and bottom of the web are for installing Moire fringe glass panels. Figure 36 shows shear web #3 with its longitudinal stiffener attached.

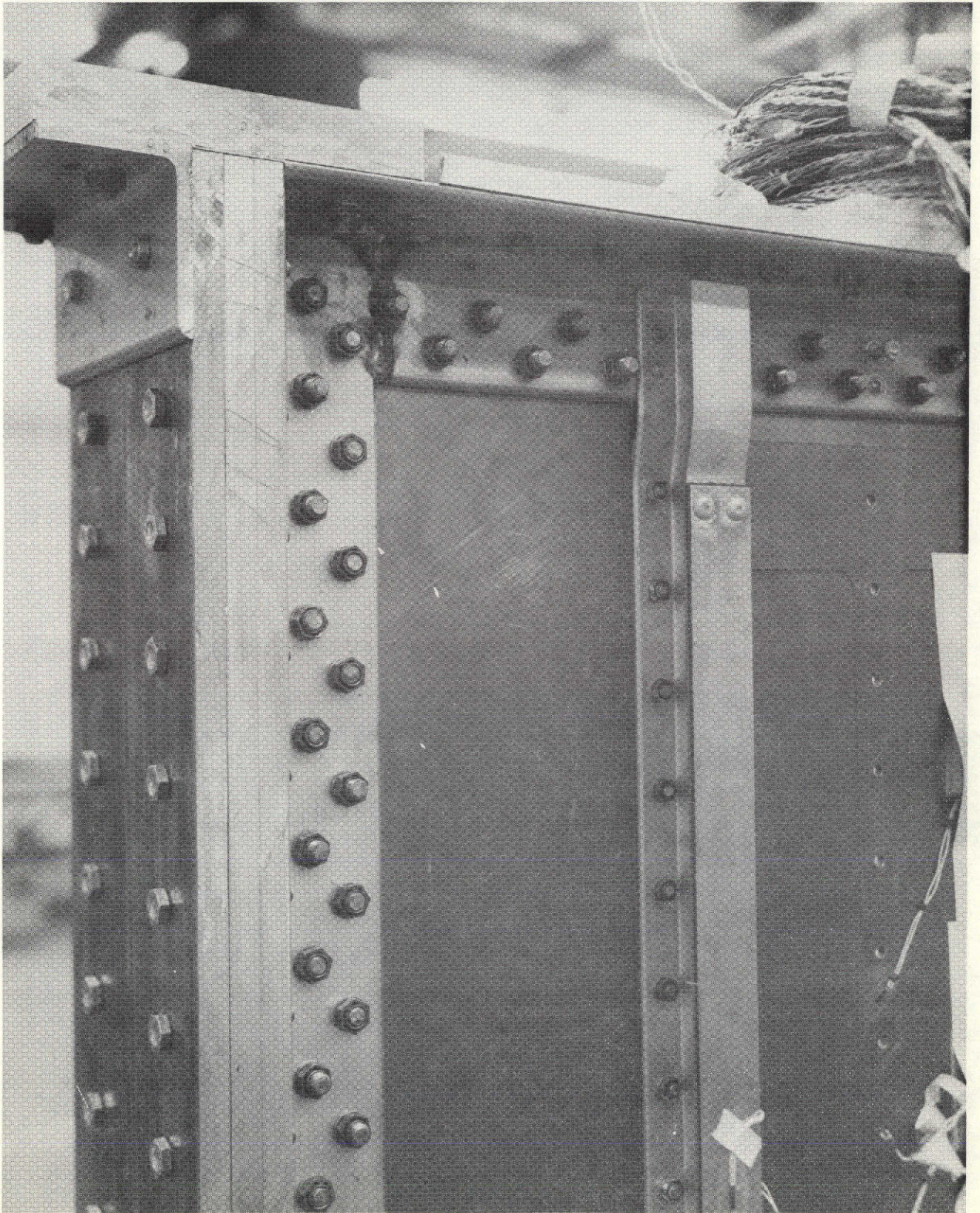


Figure 34 : STIFFENER ATTACHMENT TO TEST FIXTURE

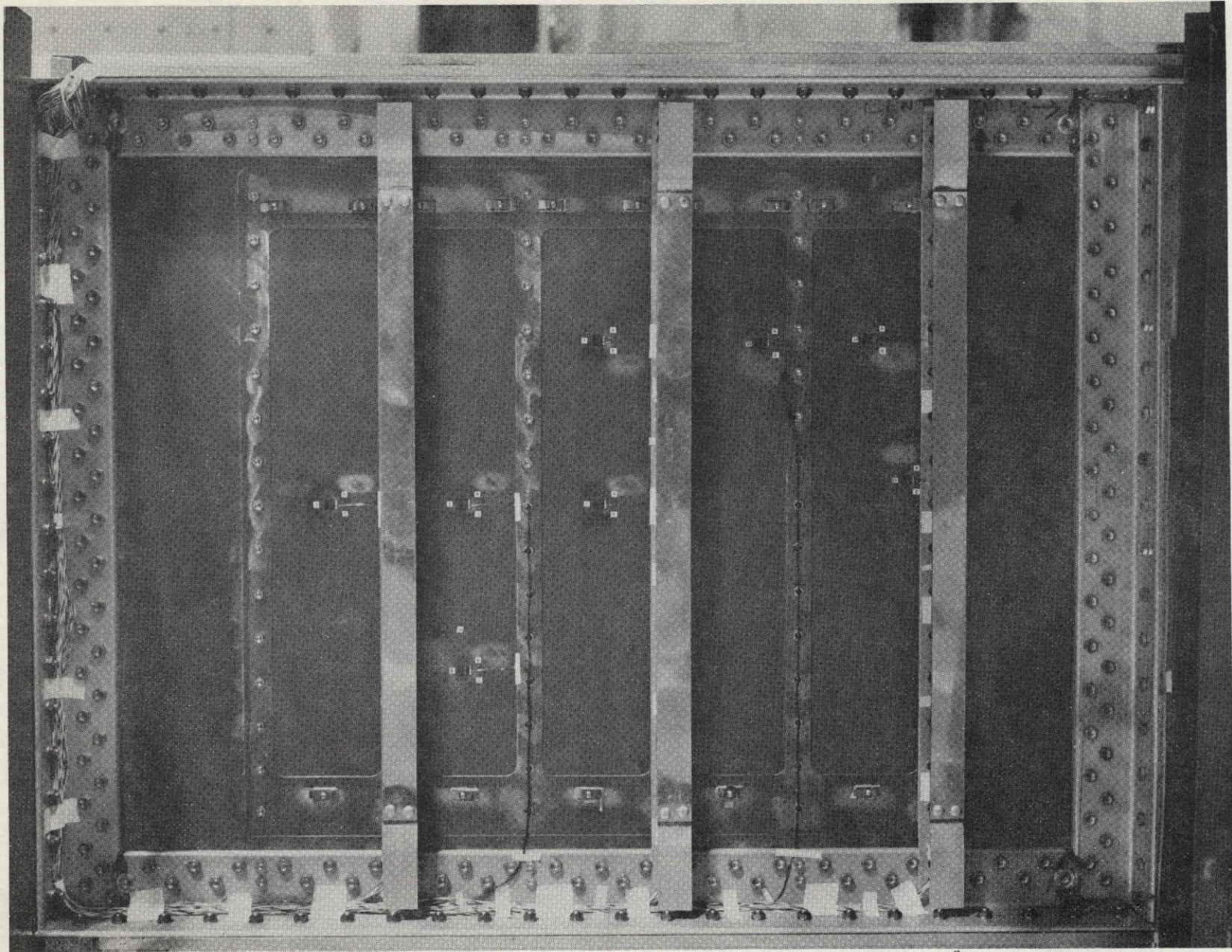


Figure 35 : COMPLETED LARGE SCALE SHEAR WEB COMPONENT #2

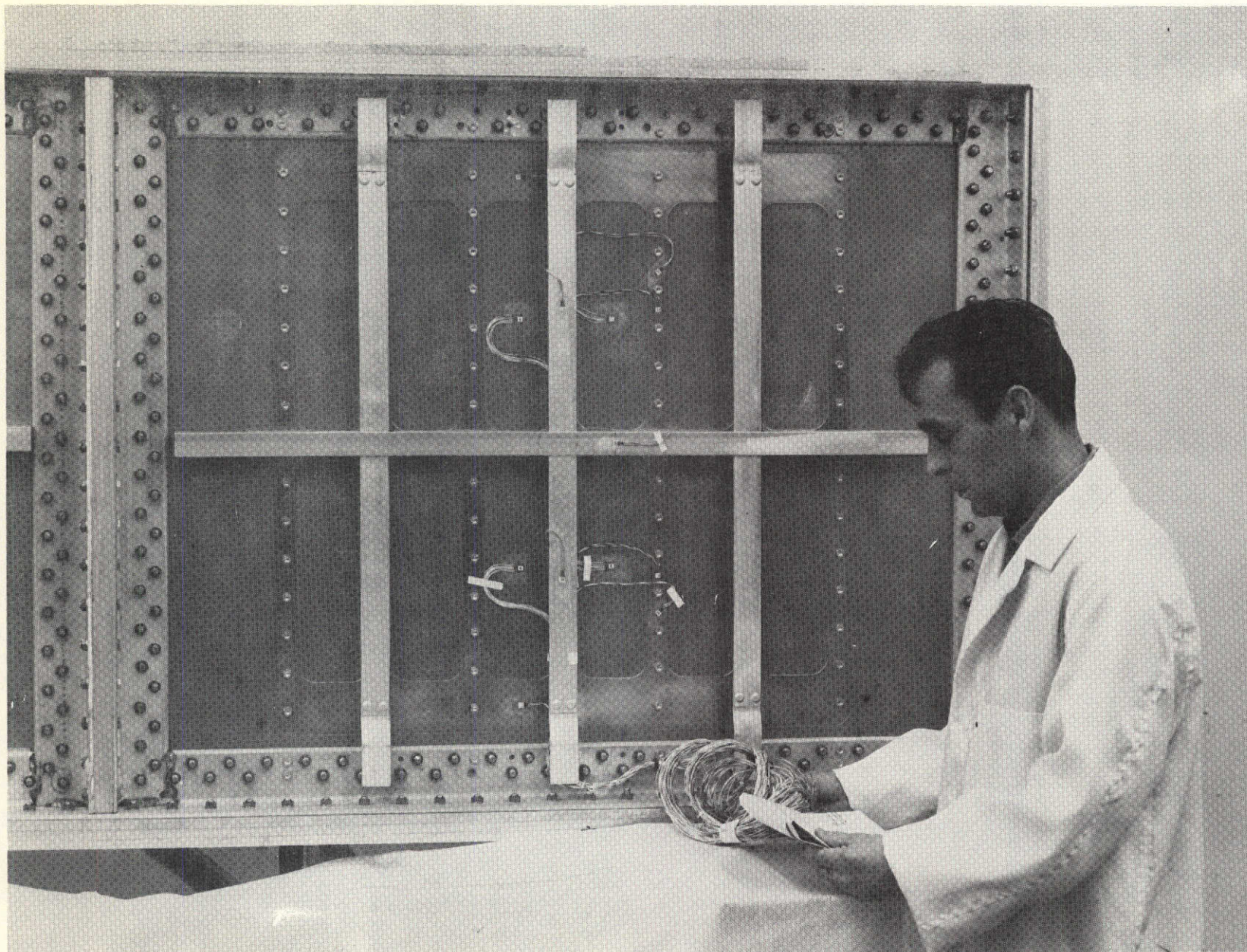


Figure 36: COMPLETED LARGE SCALE SHEAR WEB COMPONENT #3

9.0 CONCLUSIONS

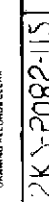
- A. The methods and processes utilized in the fabrication of three 36 in. x 47 in. shear web test components are considered amenable to full scale production hardware. Simplicity of the concept and minimal tooling requirements are considerations of the design that make it adaptable to automatic tape-laying techniques.
- B. Web panel flatness within the desired tolerance limits (± 0.005 in.) can be achieved by insuring that the panel is affected uniformly by thermal gradients during the bonding operation.
- C. The four segment spliced step-lap transition frame was verified structurally during Phase I testing. Phase II activities demonstrated that it is a fabricable concept with material cost savings over a full size, one-piece frame.
- D. Ultrasonic scanning and radiography are effective nondestructive test techniques that have demonstrated excellent Q.C. inspection capabilities for the selected concept.
- E. Improved B/E reinforced aluminum stiffener straightness can be achieved by mechanically fastening the precured B/E laminate to the stiffener prior to bonding. Additional development work on stiffener straightness is necessary to achieve a fabrication process suitable for production.

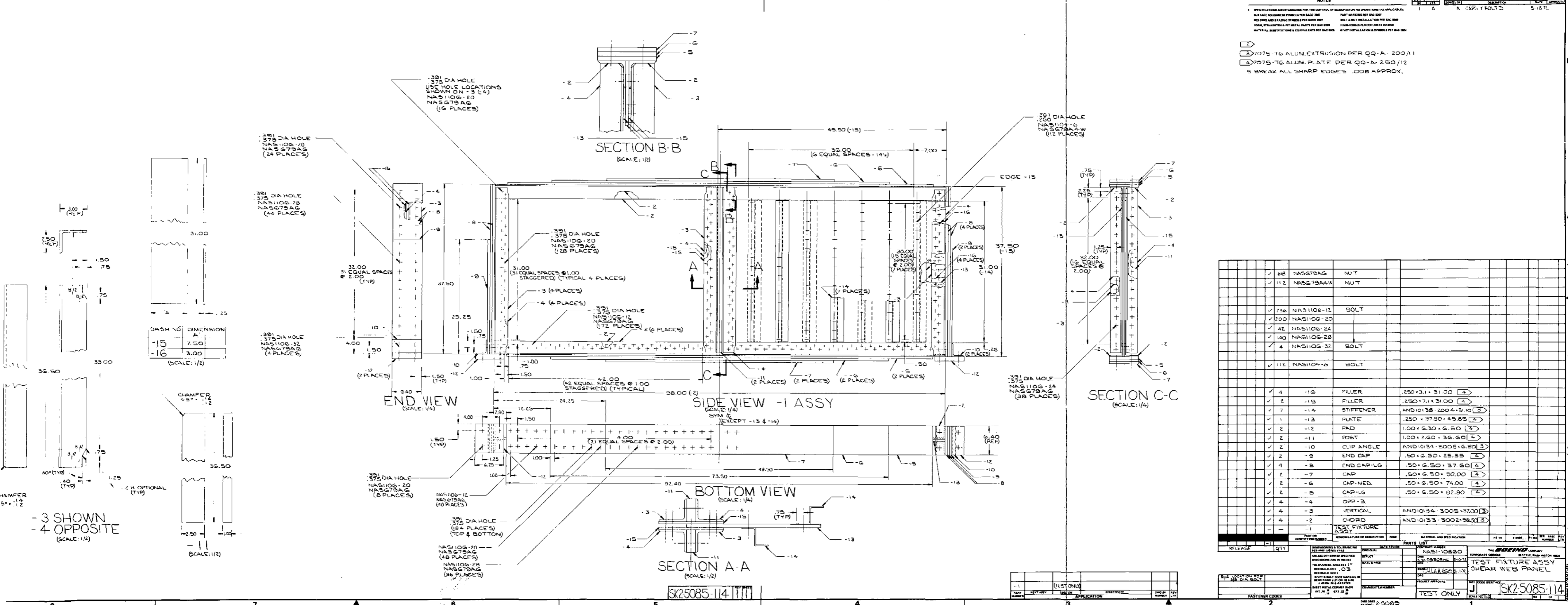
- F. A satisfactory bond of the subassembly to the titanium cladding sheets is obtainable if care is taken to insure that proper cleaning and priming techniques are utilized.
- G. Close control of processing techniques and material tolerances must be maintained in order to achieve shear web thickness repeatability.

10.0 REFERENCES

1. Laakso, J. H., and Zimmerman, D. K., "Evaluation of a Metal Shear Web Selectively Reinforced With Filamentary Composites for Space Shuttle Application," Boeing Document D180-15104, prepared under contract NAS1-10860, Phase I Report, 1972.
2. Oken, S., and Zimmerman, D. K., "Evaluation of a Metal Fuselage Frame Selectively Reinforced With Filamentary Composites for Space Shuttle Application," Boeing Document D180-15175, prepared under contract NAS1-10797, Phase I Report, 1972.

APPENDIX A
ENGINEERING DRAWINGS





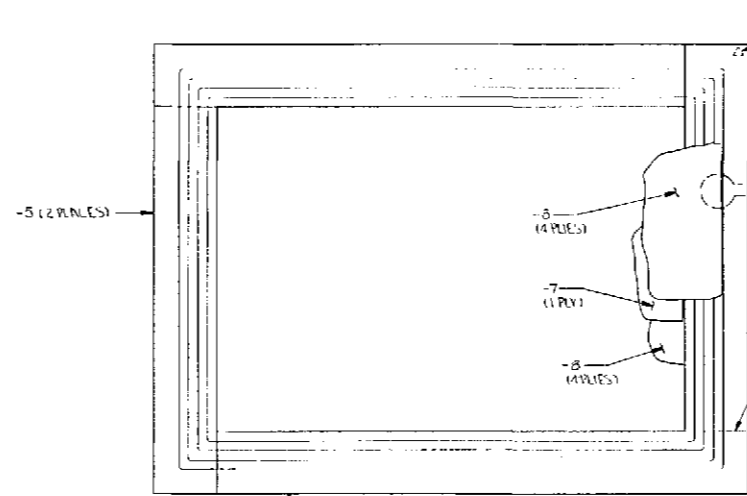
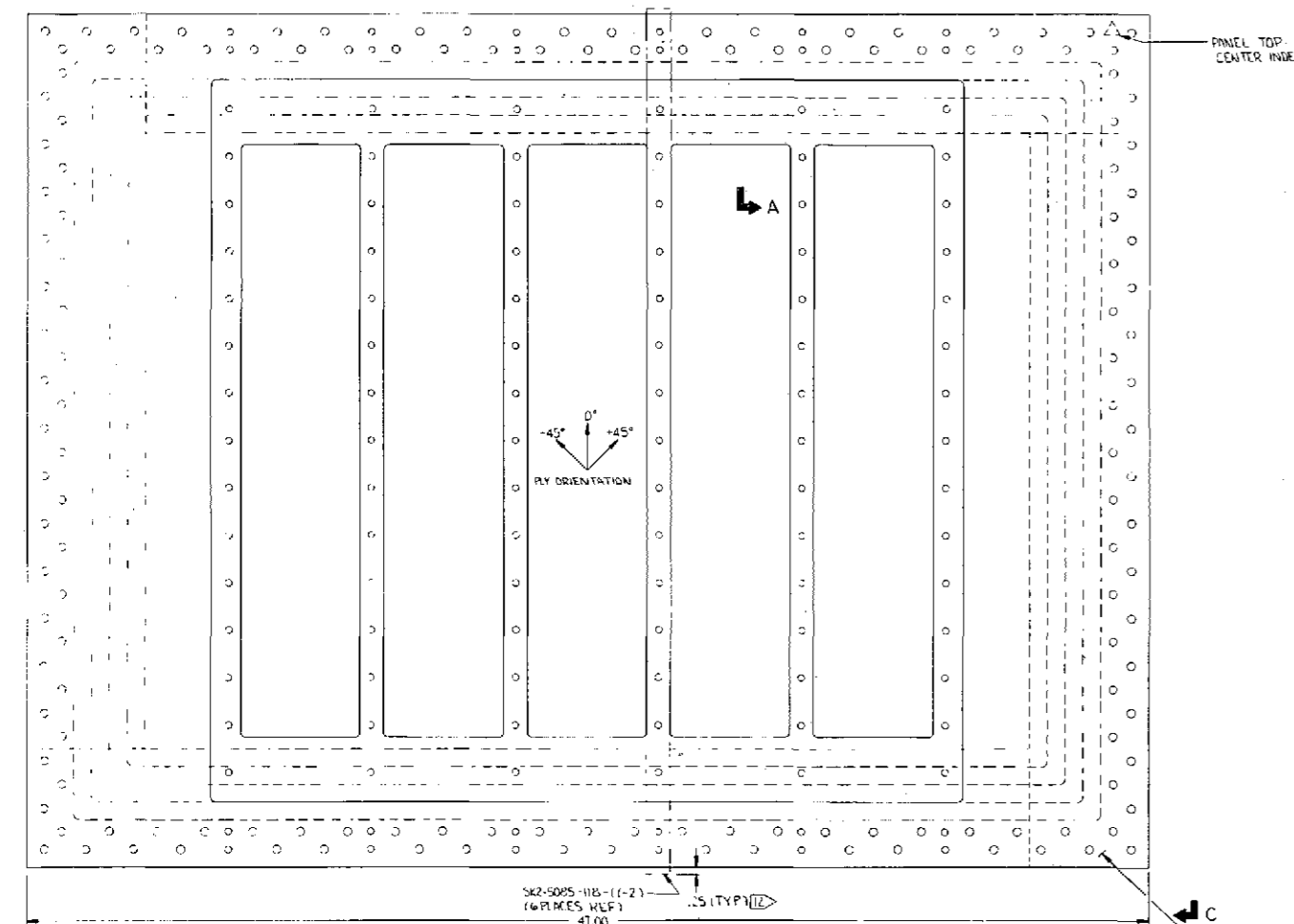
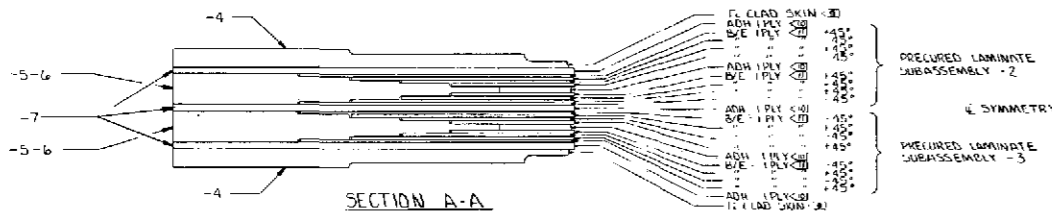
NOTES

1. SPECIFICATIONS AND STANDARDS FOR THE CONTROL OF MANUFACTURING OPERATIONS (AS APPLICABLE):
SURFACE FINISHES PER MIL-STD-1312
WELDING AND BRAZING SYMBOLS PER ASME Y32.1
FORM STRAIGHTENING PER MIL-STD-1312
MATERIAL SUBSTITUTIONS & EQUIVALENTS PER MIL-STD-1312

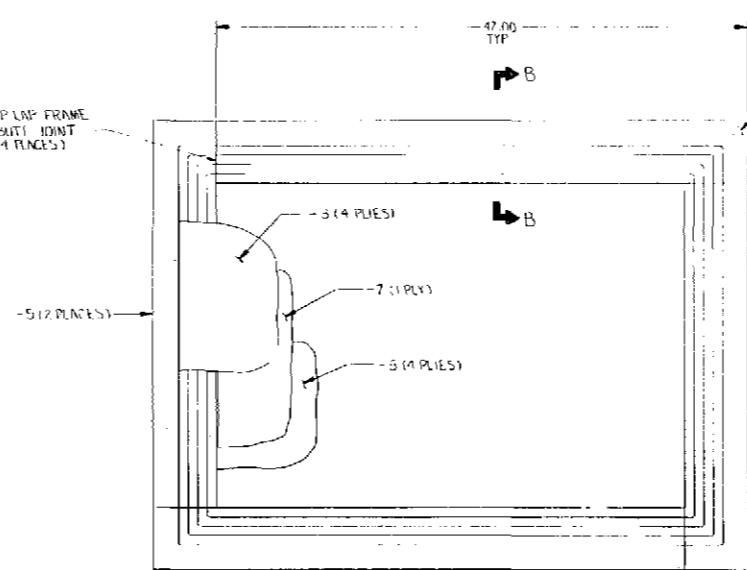
REV STATUS
ED 1 1/1

REVISIONS
DESCRIPTION
DATE APPROVED

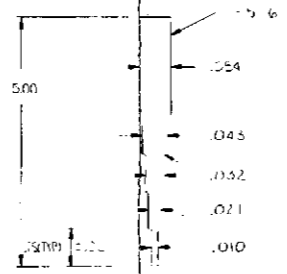
1. CHEMICAL MIL PER MIL-STD-1312
2. GENERAL MIL PER MIL-STD-1312, RADII NOTED, DUE TO THICKNESS VARIATIONS ALONG THE WORK SHEET, THE MILLED MINIMUM TOLERANCE SHOWN MAY VARY 1/16" ALONG A STEP BUT AT ANY CROSS SECTION THE STEP TO STEP THICKNESS VARIATION MUST NOT EXCEED .0005" (1/2000")
3. CLEAN THINNING DETAILS PER MIL-STD-1312, SECTION 4.2.2.4
4. SOND PER MIL-STD-1312, SECTION 4.2.2.5
5. FABRICATE PER MIL-STD-1312, SECTION 4.2.2.1
6. SURFACE FINISH PER MIL-STD-1312, AND IN ANY CASE ONLY REQUIRE FINGER PRESSURE TO GIVE CONTINUOUS CONTACT OF THE FINISH MATERIALS
7. TITANIUM 6AL 4V SHEET MIL ANNEALING (0.05" X 36" X 48")
8. TITANIUM 6AL 4V SHEET MIL ANNEALING (0.05" X 36" X 48")
9. TITANIUM 6AL 4V SHEET MIL ANNEALING (0.05" X 36" X 48")
10. UNANNEALING 202 ADHESIVE
11. WHITE MODA 800 PREPREG TAP 16 PLYS TOTAL LAYER IN -1 ASSY
12. STIFFENER LOCATED - DRILL STIFFENER ATTACHMENT HOLE TO MATCH



-3 ASSY
STEP LAP FRAME - FAR SIDE
(SCALE 1/4)



-2 ASSY
STEP LAP FRAME - NEAR SIDE
(SCALE 1/4)

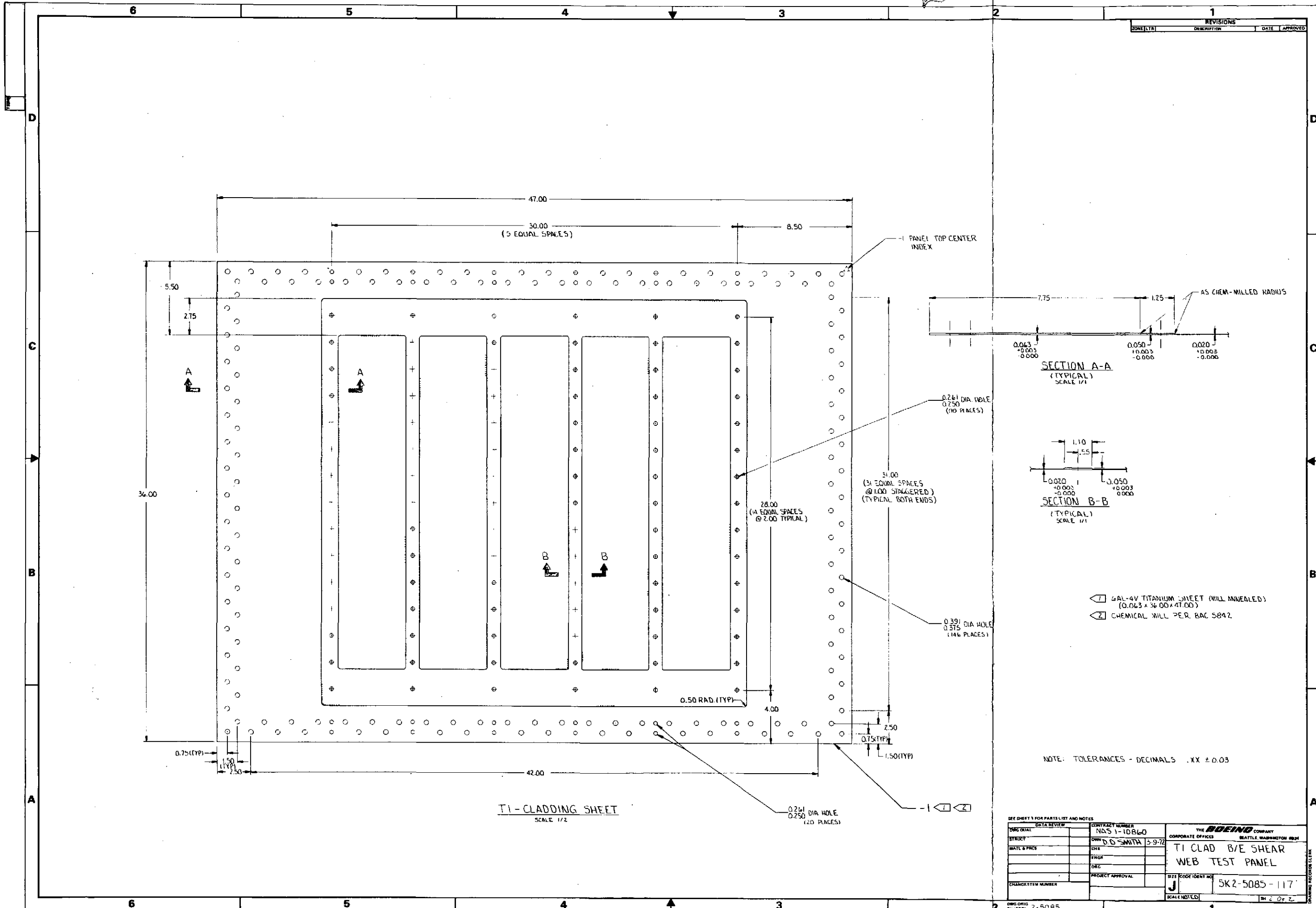


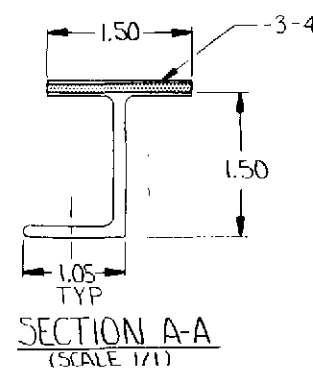
ALTERNATE
SECTION B-B
(NO SCALE)

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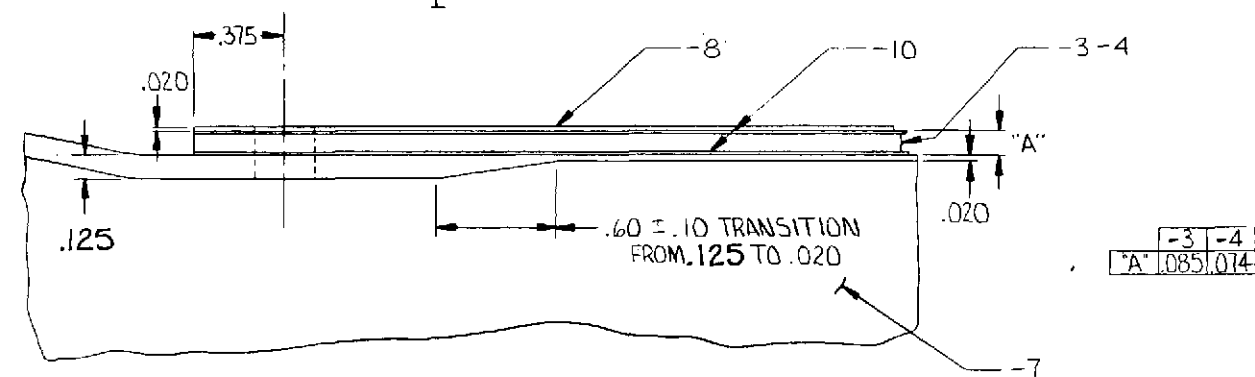
REV	DATE	BY	CHKD	DESCRIPTION
1	1/1	1	1	1

REV	DATE	BY	CHKD	DESCRIPTION
1	1/1	1	1	1

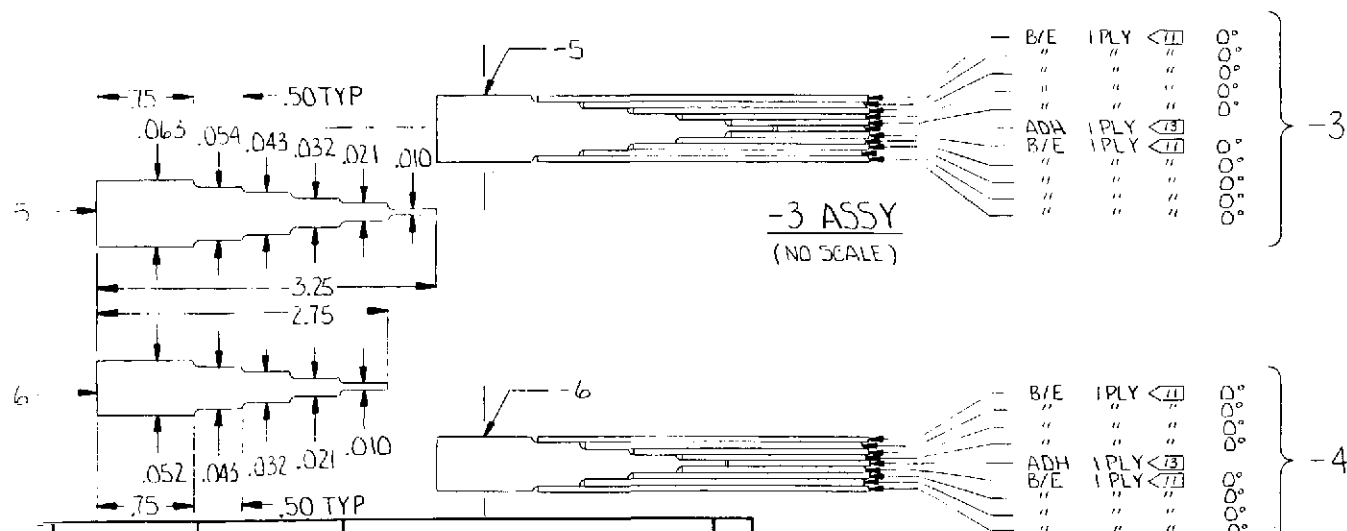




- ① CHEMICAL MILL PER BAC 5842. RADIUS AS ETCHED. DUE TO THICKNESS VARIATIONS ALONG THE STOCK SHEET THE MILLED NOMINAL THICKNESS DIMENSIONS SHOWN MAY VARY $\pm .003$ ALONG A STEP BUT AT ANY CROSS SECTION THE STEP-TO-STEP THICKNESS VARIATION MUST NOT EXCEED $.0055 \pm .001$ IN.
- ② CLEAN TITANIUM DETAILS PER DL6-23841 TN, SECTION 6.4.2.d
- ③ BOND PER DL6-23841 TN, SECTION 6.8.2.2
- ④ BOND PER BAC 5514-551 AT MINIMUM CURE TEMPERATURE.
- ⑤ REFER TO MANUFACTURING PLAN FOR ASSEMBLY DETAILS
- ⑥ STIFFENER ATTACHMENT HOLE PATTERN LOCATED. FOR HOLE PATTERN SEE DWG SK2-5085-117 SHEET 2
- ⑦ TITANIUM 6AL-4V SHEET $.063 \times 3.25 \times 1.50$
- ⑧ TITANIUM 6AL-4V SHEET $.063 \times 2.75 \times 1.50$
- ⑨ 7075-T6 ALUMINUM EXTRUSION
- ⑩ BMS 5-51, TYPE 2, GRADE 5
- ⑪ RIGIDITE 5505/4 B/E PREPREG TAPE
- ⑫ 7075-T6 ALUMINUM SHEET $.020 \times 1.50 \times 28.0$
- ⑬ NARMCO METABOND 329 ADHESIVE
- ⑭ CLEAN ALUMINUM PARTS PER BAC 5514
- ⑮ PRIME ALUMINUM PARTS WITH BMS 5-51, TYPE 1, PER BAC 5514-551



DETAIL I
(NO SCALE)



✓	✓			1RY		-11	ADHESIVE	13									
		✓	✓	ZPLIES		-10	ADHESIVE	10									
	✓			NO PLIES 8 PLIES		-9	BORON/EPOXY	11									
✓						-8	CLADDING	2	14	15							
✓	✓			1		-7	STIFFENER	AND 10140-1403×36.0	9	14	15	T6					
✓				2		-6	STEP LAP FITTING	1	2	8							
	✓			2		-5	STEP LAP FITTING	1	2	7							
-		✓		1		-4	LAMINATE ASSY	3									
	-		✓	1		-3	LAMINATE ASSY	3									
		-				-2	BOND ASSY	4	5								
			-			-1	BOND ASSY	4	5								
-4	-3	-2	-1	QTY REQD	CODE IDENT NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION		MATERIAL AND SPECIFICATION			HT TR	FINISH	PT MK	SERIALIZATION BASE NUMBER	REV LTR	
								PARTS LIST									

-2		TEST ONLY		
-1		TEST ONLY		
ART NUMBER	NEXT ASSY	USED ON	EFFECTIVITY	REV LTR
	APPLICATION			

	FASTENER CODES

**DIMENSIONING & TOLERANCING PER
ANSI (UNLESS) Y14.5**

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES

TOLERANCES: ANGLES ±

DECIMALS .XX ± .03

DECIMALS .XXX ± .003

RIVET & BOLT ELEV. MARK ± .05

BEND RADI $\pm .01$ ON .03 & .06

± .03 ON .09 & GREATER

SHEET METAL CORNER RADII

INT .16-.19 EXT .22-.26

 .14 .20

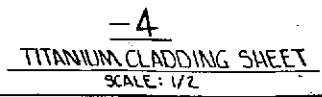
DATA REVIEW	
DRPG QUAL	
STRUCT	
MATL & PRCS	
CHANGE/ITEM NUMBER	

CONTRACT NUMBER	
NAS 1-10860	
DWN	D.D SMITH 3-16-72
CHK	
ENCR	
O'IG	
PROJECT APPROVAL	

THE **BOEING** COMPANY
CORPORATE OFFICES SEATTLE, WASHINGTON 98124

TITANIUM CLAD BORON/EPOXY
SHEAR WEB TEST PANEL
-STIFFENER

SIZE D	CODE IDENT NO. A	SK2-5085-118
SCALE NOTED		SAT 1 OF 1



APPENDIX B
MANUFACTURING PLAN

- B-1 TITANIUM COMPONENT PREPARATION
- B-2 PROCEDURE FOR LAY-UP OF BORON/EPOXY SUBASSEMBLIES
- B-3 PROCEDURE FOR FINAL ASSEMBLY BONDING
- B-4 PROCEDURE FOR STIFFENER FABRICATION

APPENDIX B - MANUFACTURING PLAN

B-1 Titanium Component Preparation

- a. Chemical-mill step details to engineering drawing per BAC 5842.
Parts that fail to meet the specified step-to-step thickness tolerance shall be rejected.
- b. Part cladding sheets to net size.
- c. Chemical-mill cladding sheets to engineering drawing per BAC 5842.
- d. Trim step-lap frame details to size.
- e. Prefit step-lap frame details and cladding sheets on assembly tool.
Stack drill locating pin holes and stiffener attachment holes in B/E laminate area.
- f. Clean step-lap frame details per BAC 5748, Rev. F, Type II, Class 1 (grit blast), followed by a dry, filtered air blast and a silane rinse.
- g. Clean cladding sheets and lap shear specimen parts per BAC 5514, Section 7.4.6 (Phosphate Fluoride Conversion Coating).
- h. Prime all faying surfaces with EC 2333 primer. Apply by brush, roller or spray to give a dried thickness of 0.00001 to .0002 inches. Air dry for 30 min. Force dry at 160°F for 30 min. (Note: Storage of primed details shall not exceed 14 days.)
- i. Protect primed surfaces from contamination by bagging or wrapping with suitable material. Cladding sheets will be bagged or wrapped separately with lap shear specimen parts identified with each panel.

APPENDIX B

B-2 Procedure for Lay-up of Boron/Epoxy Subassemblies

- a. Withdraw the designated roll of prepreg from storage. Enter roll and lot numbers, time and date removed from storage on prepreg record sheet. Allow approximately 30 minutes prior to usage to allow prepreg to warm to ambient temperature.
- b. Trim each ply of prepreg to size in accordance with the appropriate engineering drawing. Use a paper cutter for cuts transverse to the filament direction. Trim to width with a sharp blade cutting parallel to the filaments.
- c. Inspect primed faying surfaces on step-lap details. If storage time exceeds 14 days or if visual inspection dictates, reclean parts and apply primer per B-1(h).
- d. Position titanium step-lap frame details according to engineering drawing on locating tool with filler panel in place. Apply teflon separation film over filler panel.
- e. Remove protective backing from prepreg and lay the first ply with the adhesive side down. Place tapes edge to edge as required to generate the width needed.
- f. Remove the protective backing from subsequent plies of prepreg and lay with the adhesive side down. Overlay each ply with a clean plastic separator and sweep or roll with a rubber roller to compact laminate, working out as much air as possible.

- g. Repeat above until the drawing specified number of layers have been applied.
- h. Lay down a net size ply of nylon peel ply (MILTEX 3921 or equivalent) no wrinkles permitted.
- i. Overlay lay-up with supporting plate and flip part. Remove filler panel from lay-up.
- j. Sweep or roll with a rubber roller to insure that no voids were formed during flipping operation. Remove teflon separator film and roll adhesive to achieve intimate contact with the prepreg.
- k. Repeat steps e through h.
- l. Overlay lay-up with 1 ply of teflon separator film (51789 Nylon).
- m. Place caul plate on subassembly over locating pins.
- n. Install a minimum of 3 thermocouples on subassembly surface.
- o. Apply 4 plies of #7500 or equivalent fiberglass bleeder cloth.
- p. Cover subassembly with nylon vacuum film and seal to bonding tool.
- q. Autoclave cure per Figure 13.

APPENDIX B

B-3 Procedure for Final Assembly Bonding

- a. Inspect all components of the secondary bonding operation. All surfaces to be bonded shall be free of visual defects that will be detrimental to the bonded assembly. If storage time after priming cladding sheets exceeds 14 days or if visual inspection dictates, reclean parts and prime per B-1(h).
- b. All surfaces shall be prefitted to verify that finger pressure is sufficient to give continuous contact of the mating surfaces.
- c. Place cladding sheet, faying surface up, onto locating tool.
- d. Apply 1 ply of Metlbond 329 adhesive onto faying surface of cladding sheet, leaving no gaps.
- e. Prepare the precured subassemblies for bonding by removing the nylon peel ply from both sides immediately prior to placement onto locating tool.
- f. Locate far-side subassembly on cladding sheet over locating pins. Insure subassembly orientation complies with engineering drawing.
- g. Apply 1 ply Metlbond 329 adhesive over far-side subassembly, leaving no gaps.
- h. Locate the nearside subassembly onto locating tool. Insure subassembly orientation complies with engineering drawing.
- i. Apply 1 ply Metlbond 329 adhesive over near-side subassembly, leaving no gaps.

- j. Place cladding sheet into position, faying surface down, and apply sufficient hand pressure to tack details together.
- k. Remove assembly from the locating tool, retaining locating pins in place.
- l. Install a minimum of 3 thermocouples on the assembly surface.
- m. Cover assembly with teflon FEP parting film.
- n. Cover assembly with 1 ply #180 and 3 plies #7500 glass fabric bleeder cloth.
- o. Cover assembly with nylon vacuum bag. Impress into sealant to effect a seal.
- p. Check vacuum bag by drawing maximum shop vacuum and checking pressure drop. Pressure must not fall more than one inch of Hg per minute.
- q. Mount bagged assembly in the holding fixture in an upright (vertical) position and place in autoclave.
- r. Autoclave cure per Figure 14.

APPENDIX B

B-4 Procedure for Stiffener Fabrication

- a. Machine flanges to final dimensions.
- b. Heat treat to T6 (as quenched) condition. Do not age.
- c. Stretch straighten.
- d. Joggle per SK2-5085-118 (Appendix A).
- e. Stack drill stiffener, B/E laminate, and aluminum cover. Class 1 hole minimum.
- f. Assemble stiffener for bonding with 2 plies of BMS 5-51, Type 2, Grade 5 adhesive. Fasten together with temporary bolts (NAS 1104-3).
- g. Autoclave cure assembly per BAC 5514-551.
- h. Replace bolts with Al rivets (MS 20470 D8-4).
- i. Chemical-mill upper flange to dimension.